SCE
Data Center Efficiency
December 4, 2007

CA Public Interest Energy Research

funded through the California Energy Commission

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COURSE OBJECTIVES:

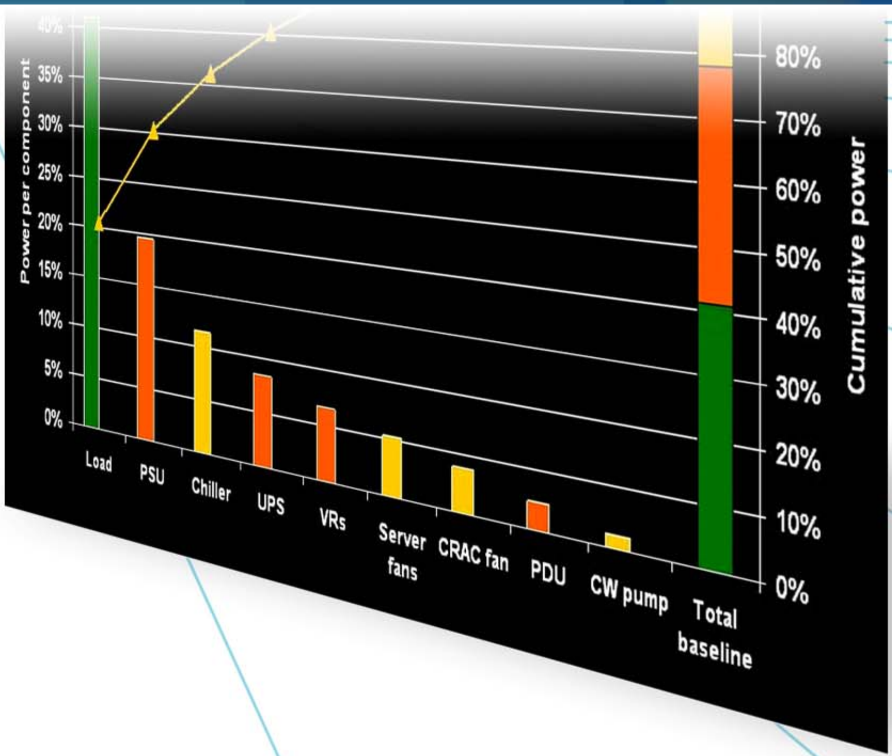
- Raise awareness of data center energy intensity and efficiency opportunities
- Provide resources for on-going use
- Provide information on SCE incentive programs
- Group interaction for common issues and possible solutions

YOU WILL LEARN ABOUT:

- Major energy use in data centers
- Opportunities to increase computational efficiency and the multiplier effect
- Energy intensity growth
- Benchmarking opportunities (how do I stack up?)
- Best practices to improve infrastructure efficiency
- Extending the life and effective capacity of existing data centers
- Technologies coming down the R&D pipeline and lessons learned from demonstrations
- Information and technical assistance resources

AGENDA

8:15	Introductions - Group Identify Problems/Interest
8: 45	Overview and Design Issues in Data Centers
9:30	HVAC Air System Issues
10:00	Break
10:15	Liquid Cooling
10:40	Electrical Distribution Issues
11:10	IT Issues
11:30	SCE Programs
12:00	Wrap-up



Overview of Data Center Energy Use

Data Center Definitions

- Server closet < 200 sf
- Server room <500 sf
- Localized data center <1,000 sf
- Mid-tier data center <5,000 sf
- Enterprise class data center 5000+ sf

Focus today's training on larger data centers—
however most principles apply to any size center

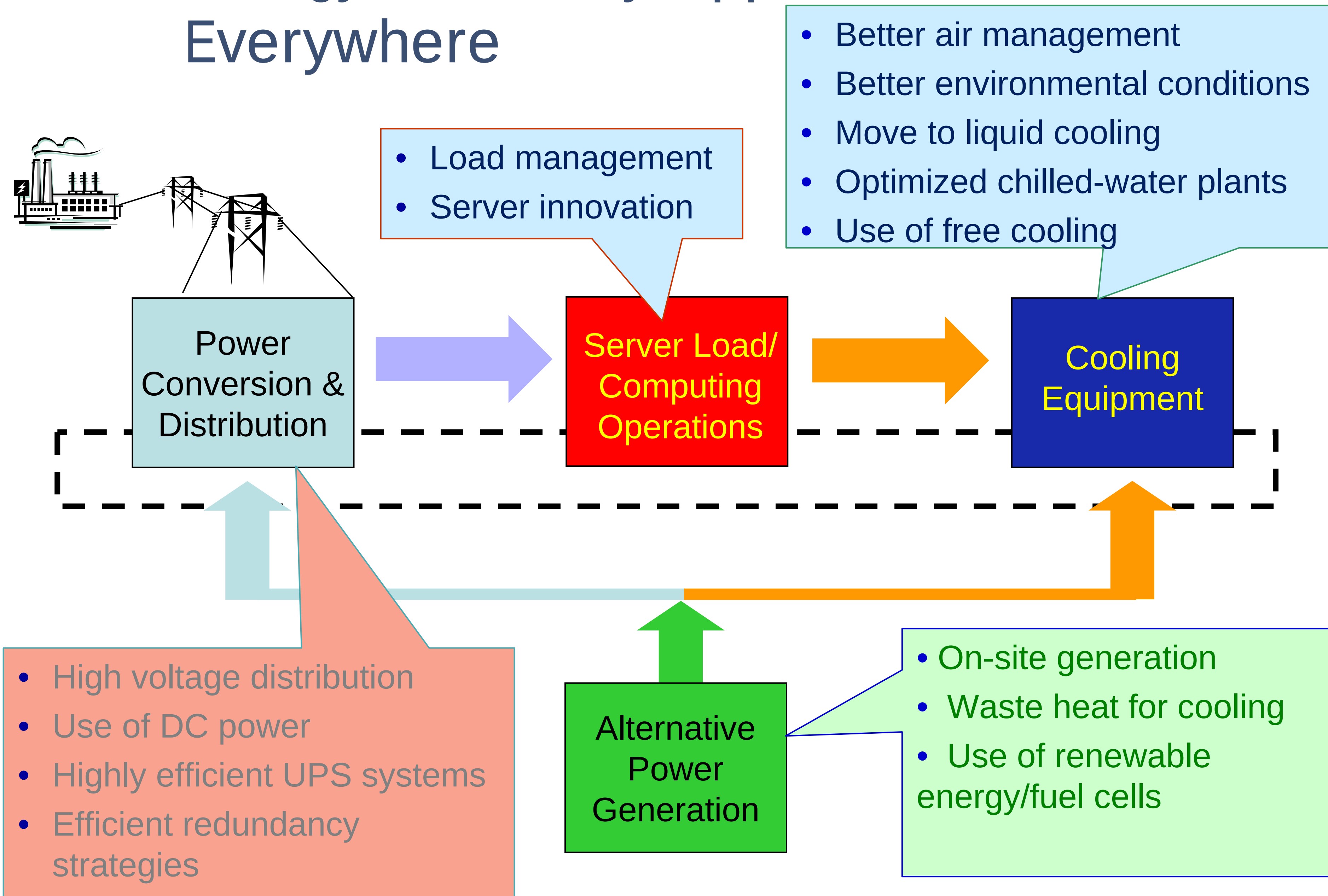
Data Center Efficiency Opportunities

Benchmarking of over 25 centers consistently lead to opportunities

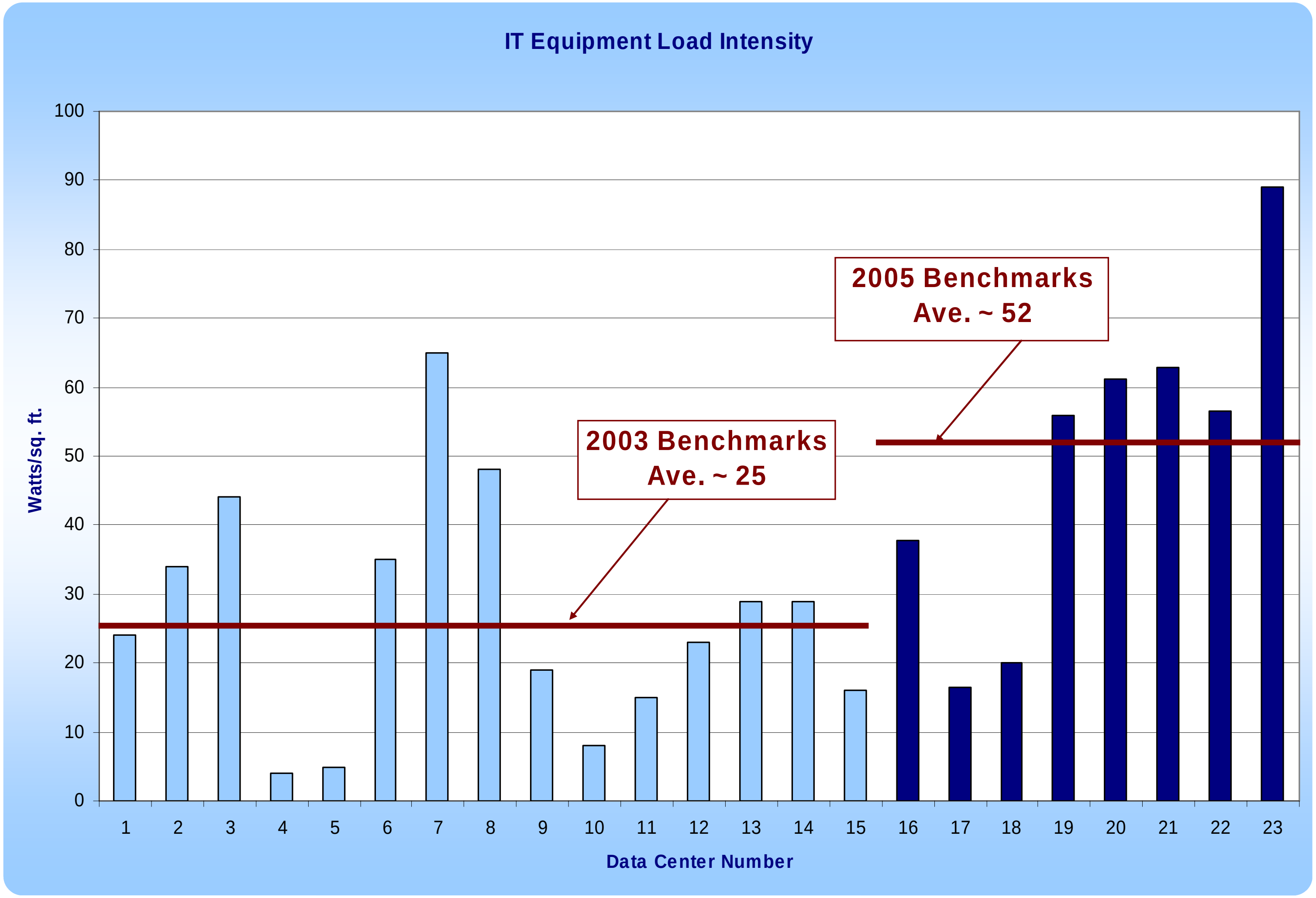
No silver bullet

Lots of silver bb's

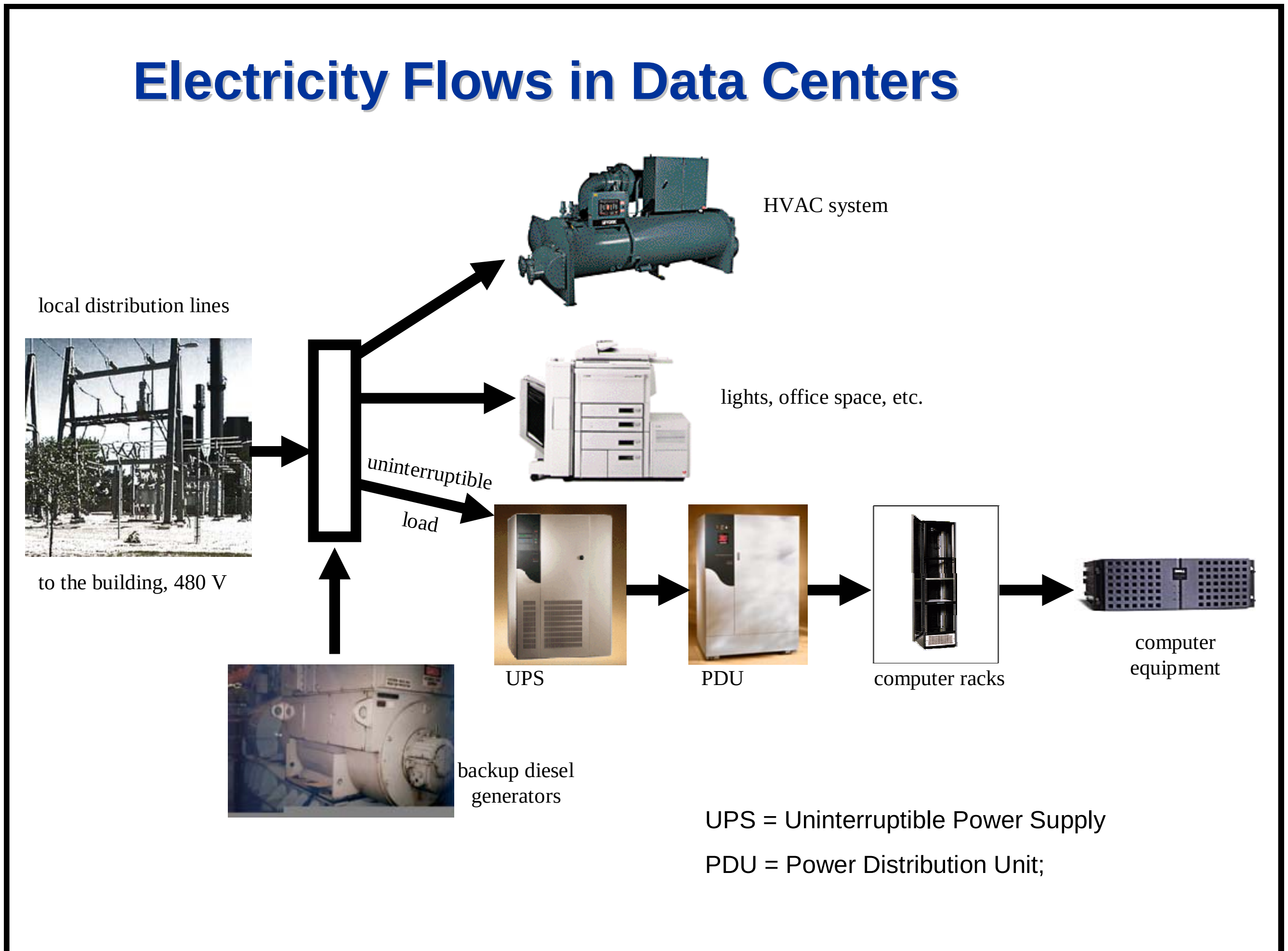
Energy Efficiency Opportunities Are Everywhere



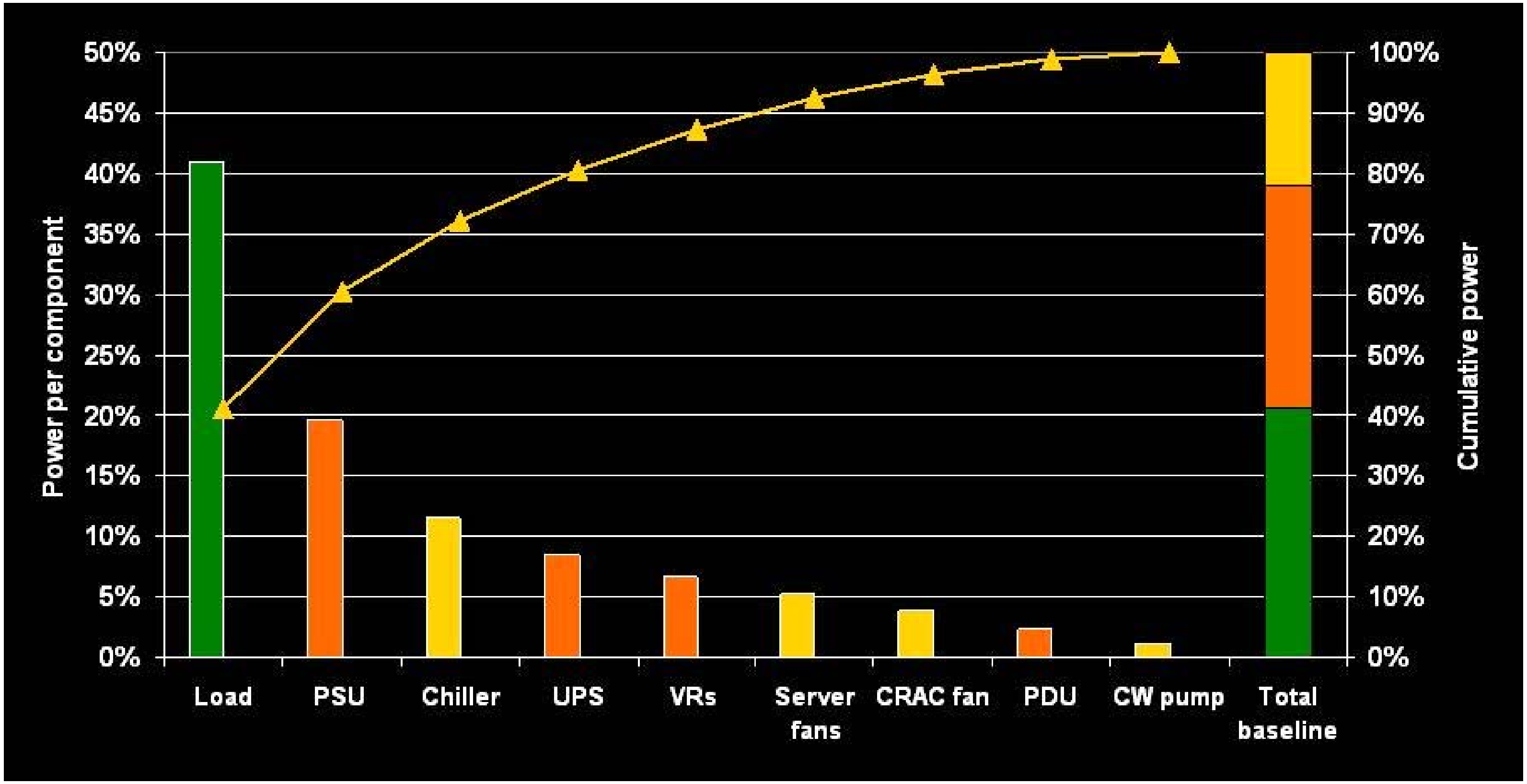
IT Equipment Load Density



Benchmarking Energy End Use



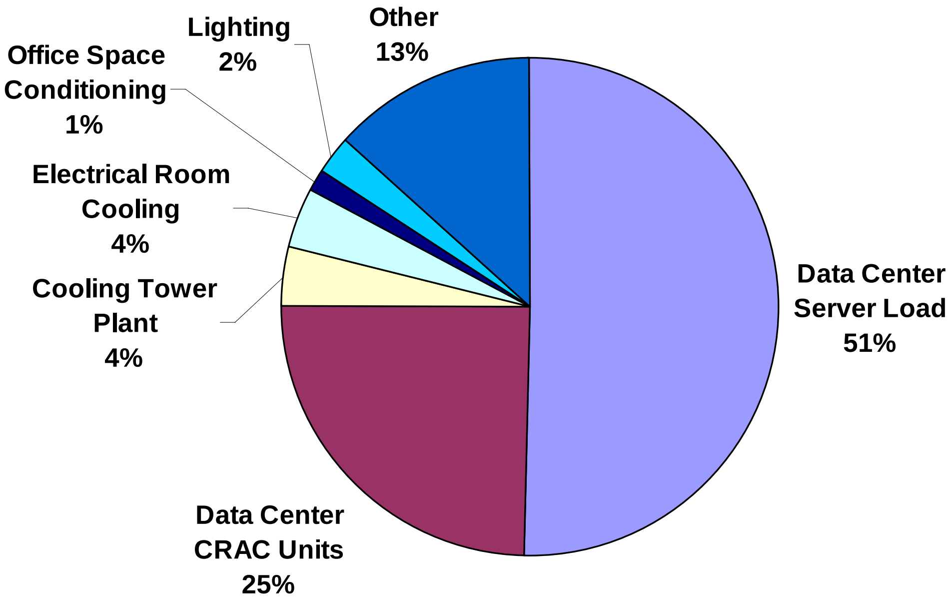
Overall Electrical Power Use in Data Centers

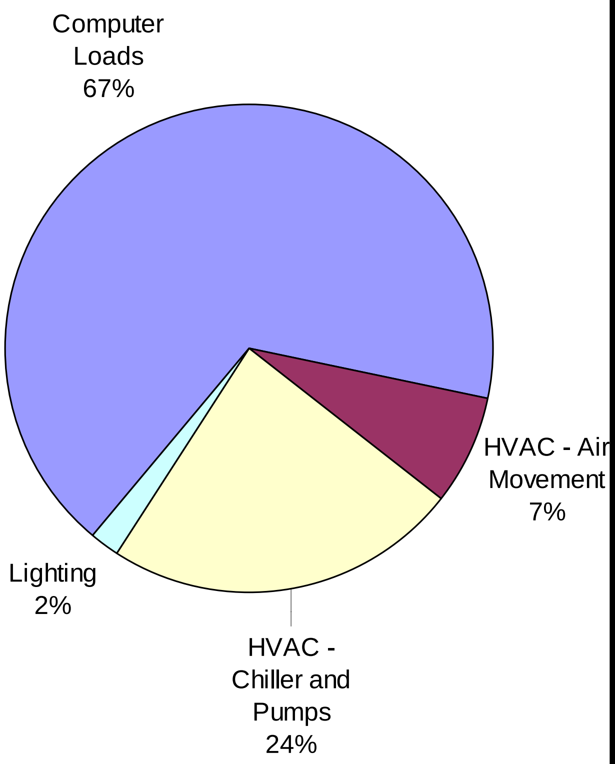


Courtesy of Michael Patterson, Intel Corporation

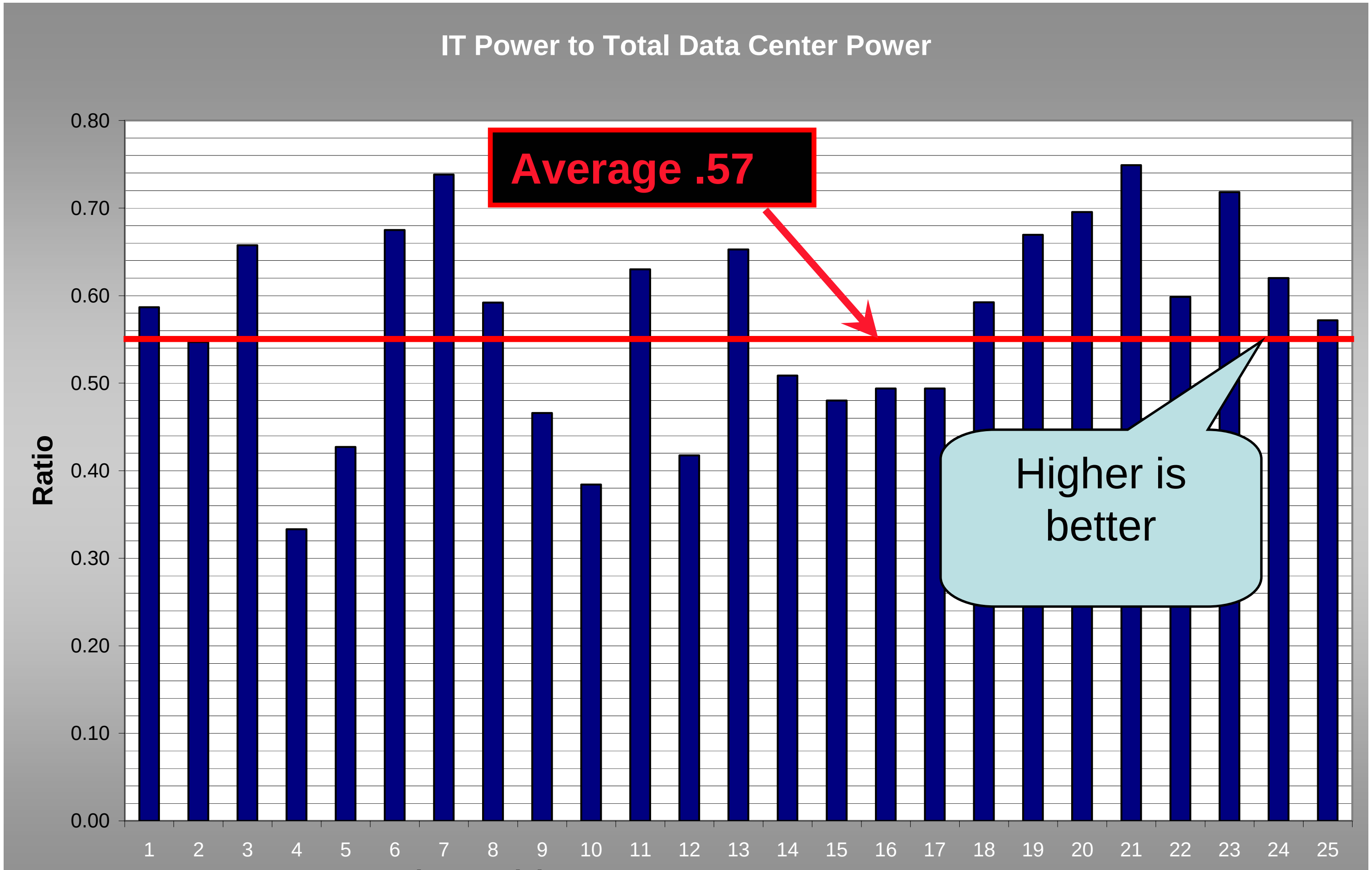
Your Mileage Will Vary

The relative percentages of the energy actually doing computing varied considerably.



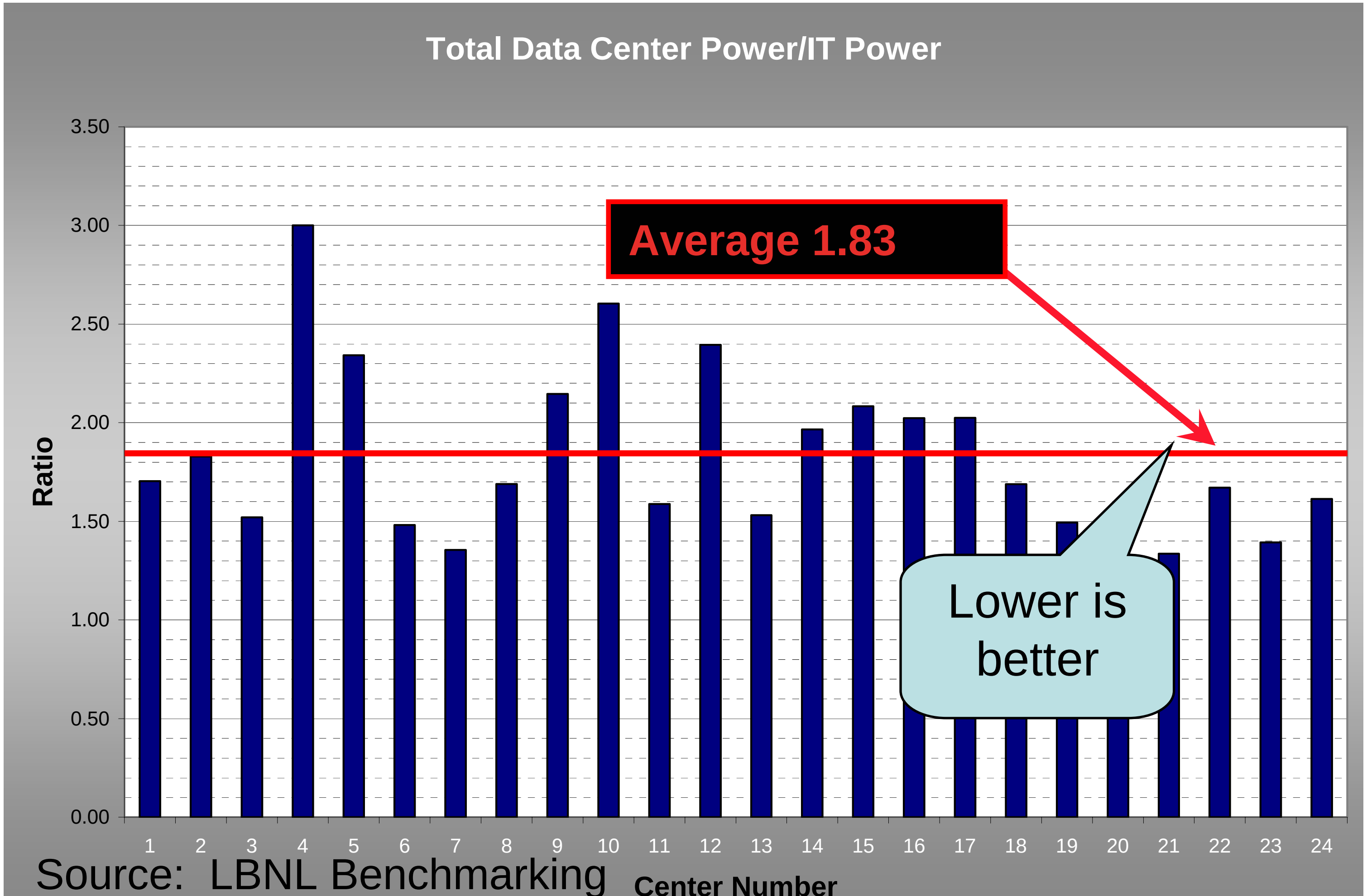


High Level Metric—
Ratio of Electricity Delivered to IT Equipment



Source: LBNL Benchmarking

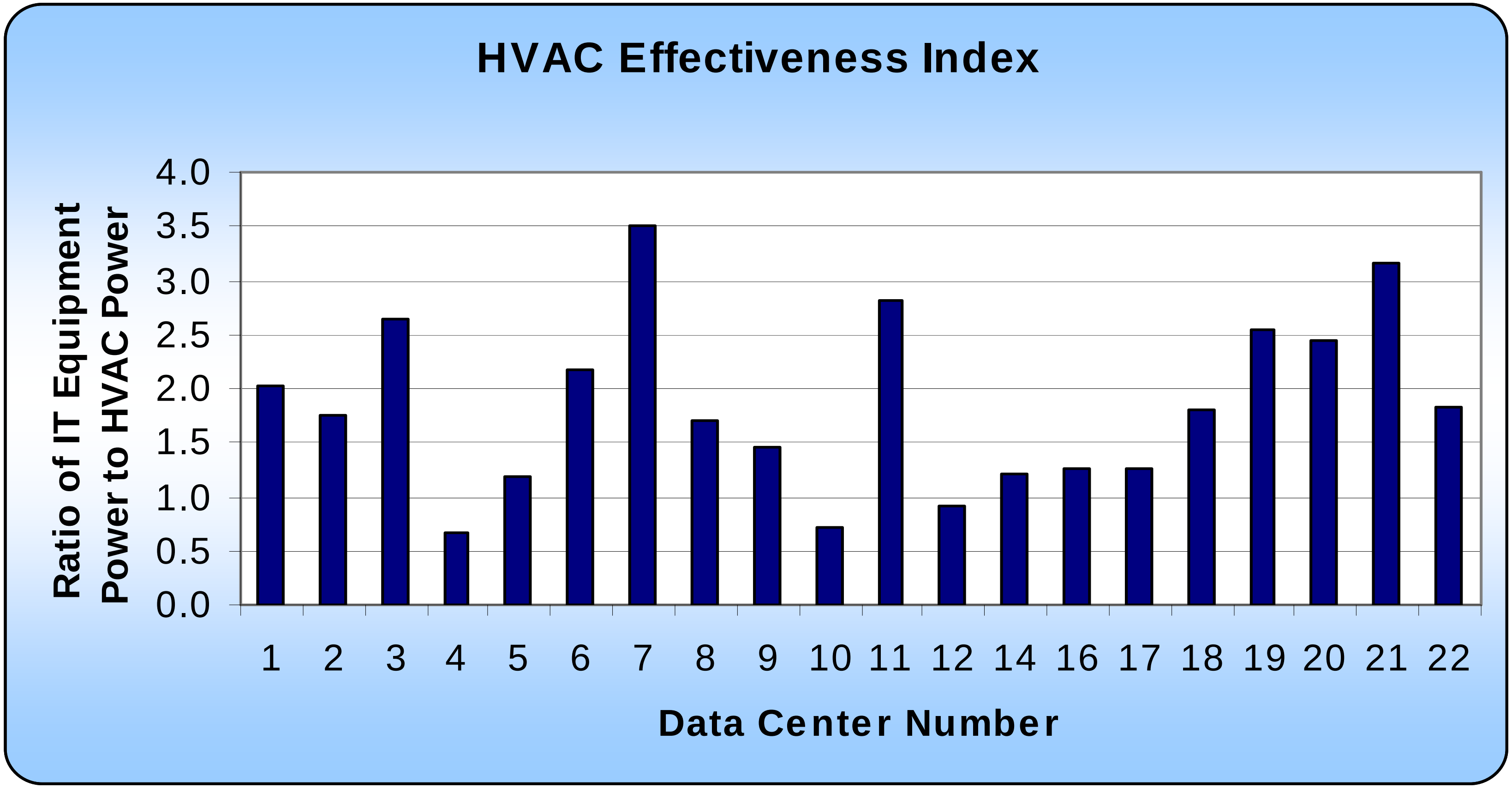
Alternate High Level Metric –
Data Center Total / IT Equipment (PUE)



Source: LBNL Benchmarking

HVAC System Effectiveness

We observed a wide variation in HVAC performance



Benchmark Results Help Identify Best Practices

The ratio of IT equipment power to the total is an indicator of relative overall efficiency. Examination of individual systems and components in the centers that performed well helped to identify best practices.

Best HVAC Practices

- Air Management
- Air Economizers
- Humidification Control
- Centralized Air Handlers
- Low Pressure Drop Systems
- Fan Efficiency
- Cooling Plant Optimization
- Water Side Economizer
- Variable Speed Chillers
- Variable Speed Pumping
- Direct Liquid Cooling

Best Electrical Practices

- UPS systems
- Self-generation
- AC-DC distribution
- Standby generation

Best Practices and IT Equipment

- Power supply efficiency
- Standby/sleep power modes
- IT equipment fans
- Virtualization
- Load shifting

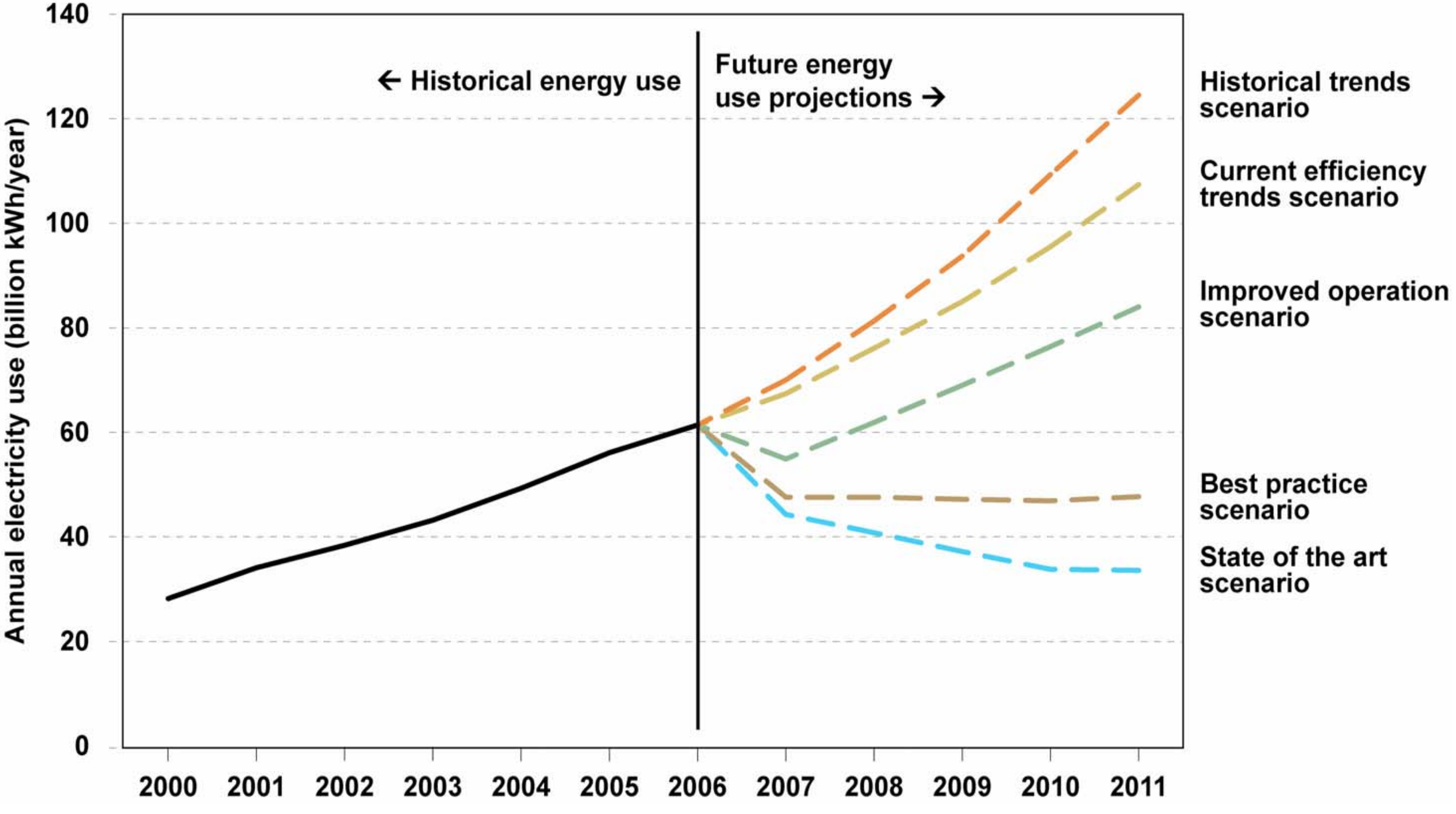
Best Practices— Cross-Cutting and Misc. Issues

- Motor efficiency
- Right sizing
- Variable speed drives
- Lighting
- Maintenance
- Continuous Commissioning and Benchmarking
- Heat Recovery
- Building Envelope
- Redundancy Strategies
- Methods of charging for space and power

Potential Savings

- Electrical bill will exceed the cost of IT equipment over its useful life
- 20-40% savings typically possible
- Aggressive strategies – better than 50% savings
- Paybacks are short – 1 to 3 years are common

Scenarios of Projected Energy Use from EPA Report to Congress 2007 - 2011



The Good News:

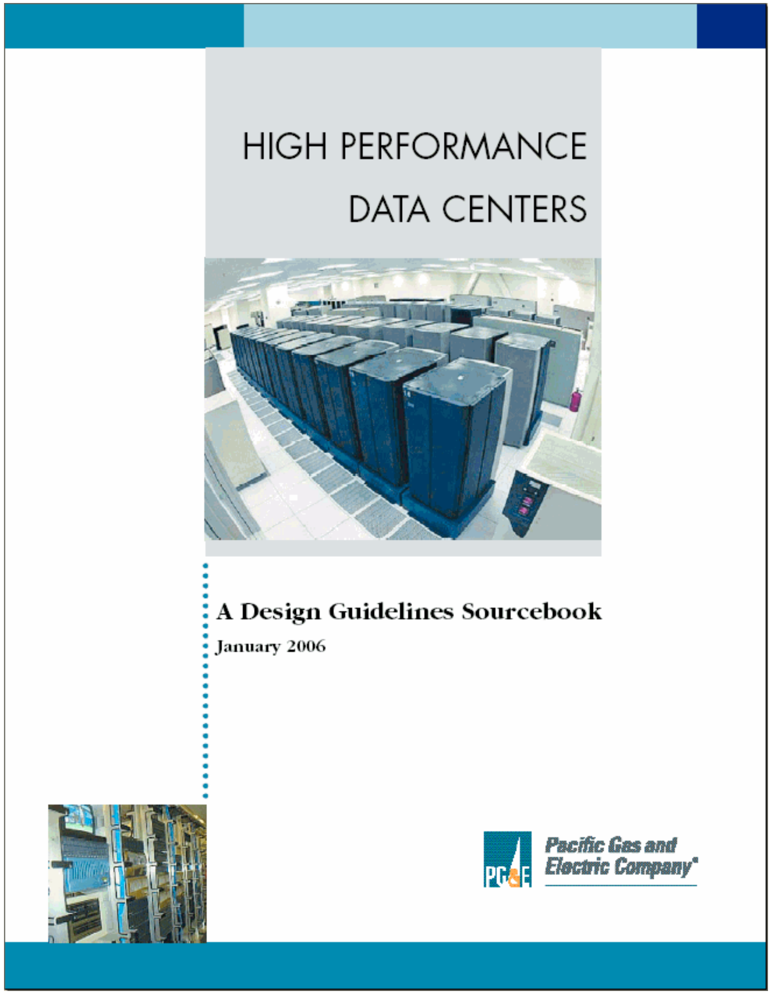
- Industry is taking action
  - IT manufacturers
  - Infrastructure equipment manufacturers
- Industry Associations are active:
  - ASHRAE
  - Green Grid
  - Uptime Institute
  - Afcom
  - Critical Facilities Roundtable
  - 7 X 24 Exchange

More Good News:

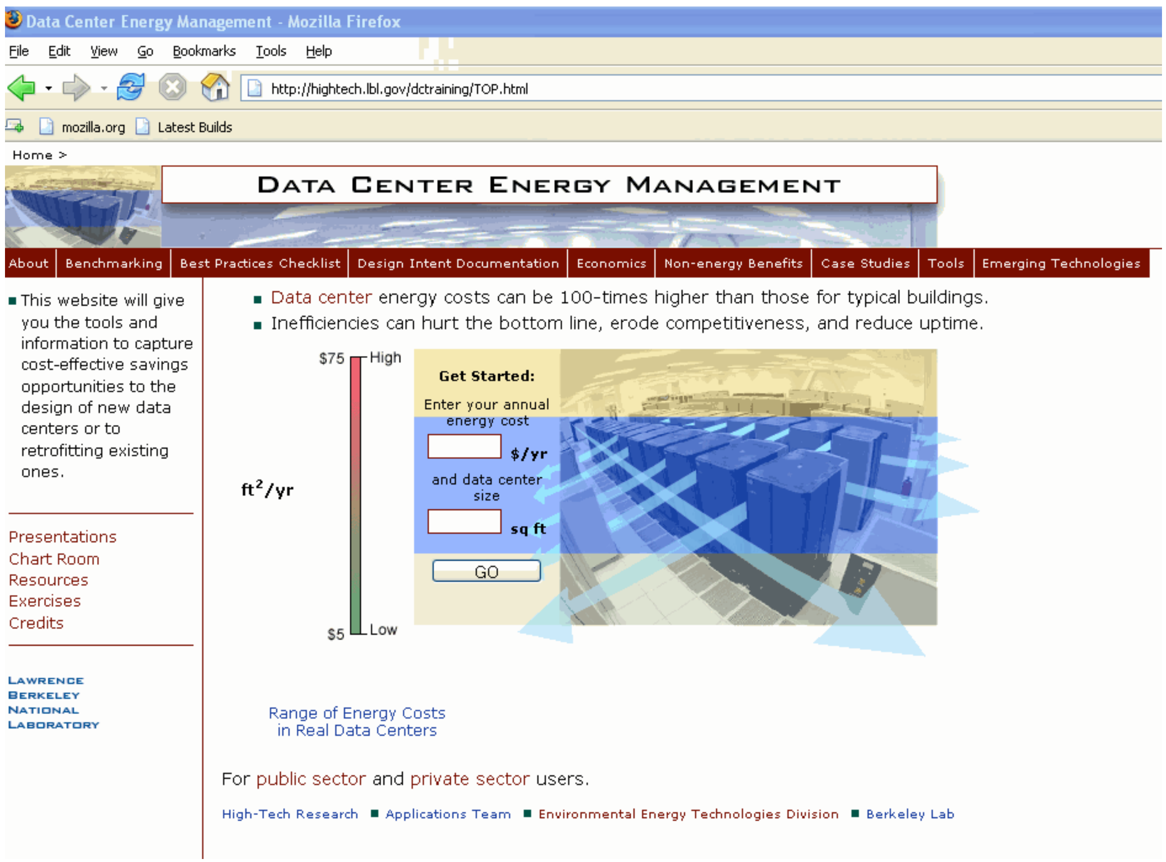
- Utilities are involved:
  - SCE, PG&E, San Diego
  - CEE
- CA incentive programs are aggressive
- California Energy Commission, DOE, EPA all have data center initiatives

Design Guidelines for Ten Best Practices Were Developed

Guides available through PG&E's Energy Design Resources Website



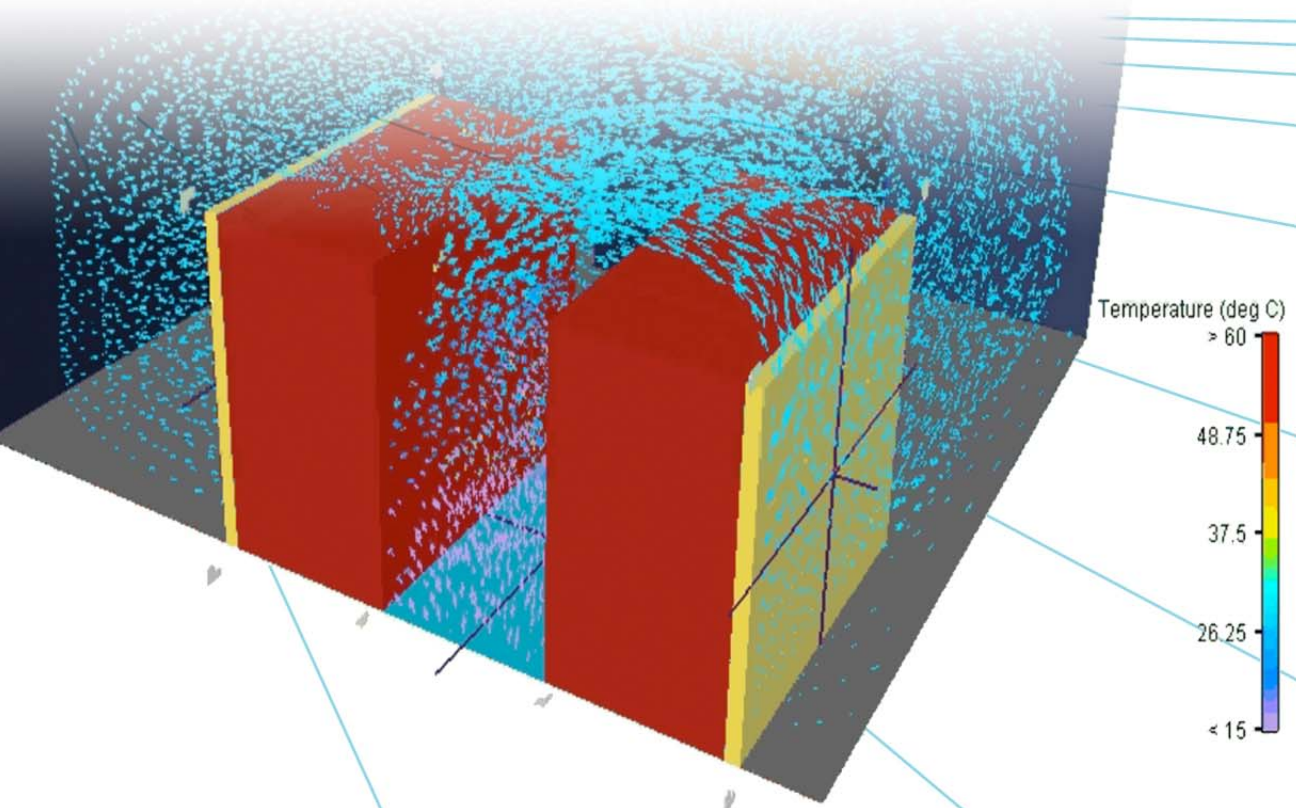
Design Guidance is Summarized in a Web Based Training Resource



http://hightech.lbl.gov/dctraining/TOP.html

Take Aways

- Various meanings for “data centers”
- Benchmarking helps identify performance
- Benchmarking suggests best practices
- Efficiency varies
- Large opportunity for savings
- Resources are available



Data Center Design Issues

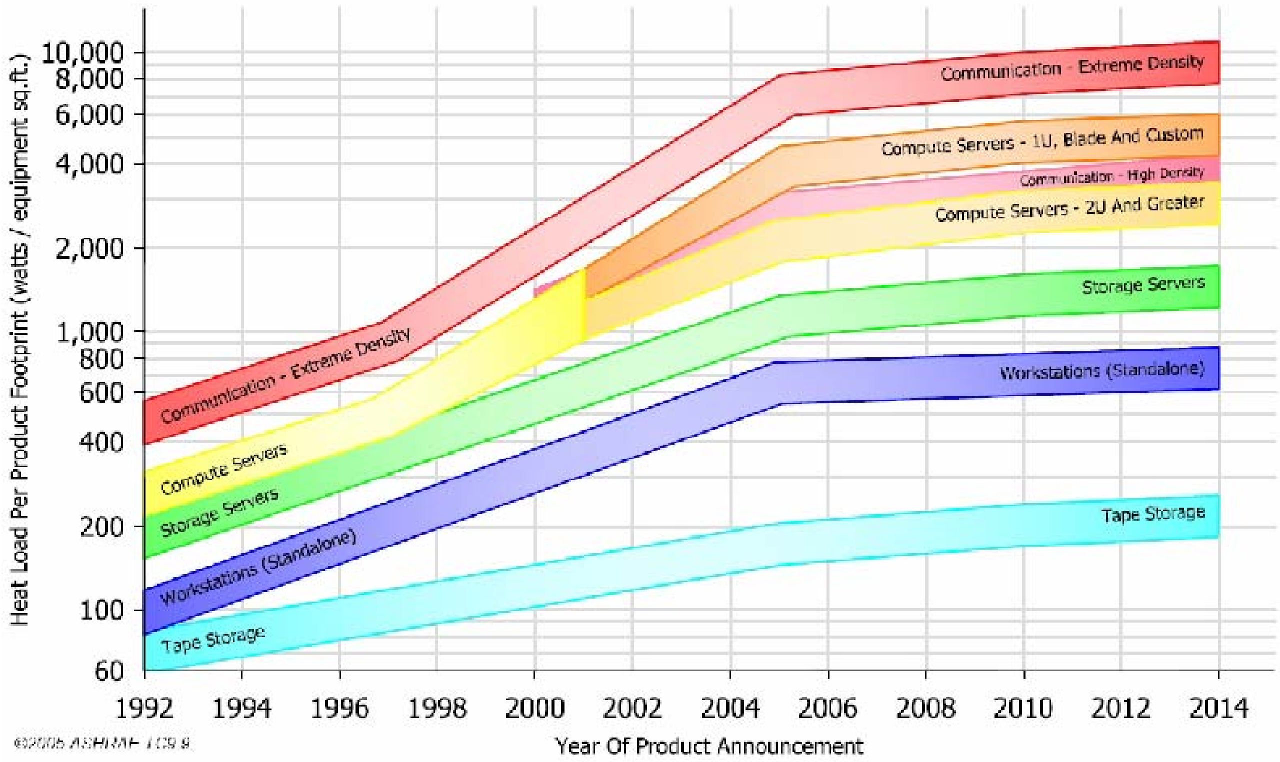
Design Issues

- IT equipment load
- Redundancy
- Data center airflow
- Environmental conditions
- Zoning
- Isolating hot and cold

IT Equipment Load

- Predicting IT loads
  - Over sizing, at least initially, is common
  - Implement modular and scalable approaches
- IT loads can be controlled
  - Power supply options
  - Server efficiency
  - Software efficiency (Virtualization, MAID, etc.)
  - Redundancy and back-up power
  - Low power modes
- Reducing IT load has a multiplier effect

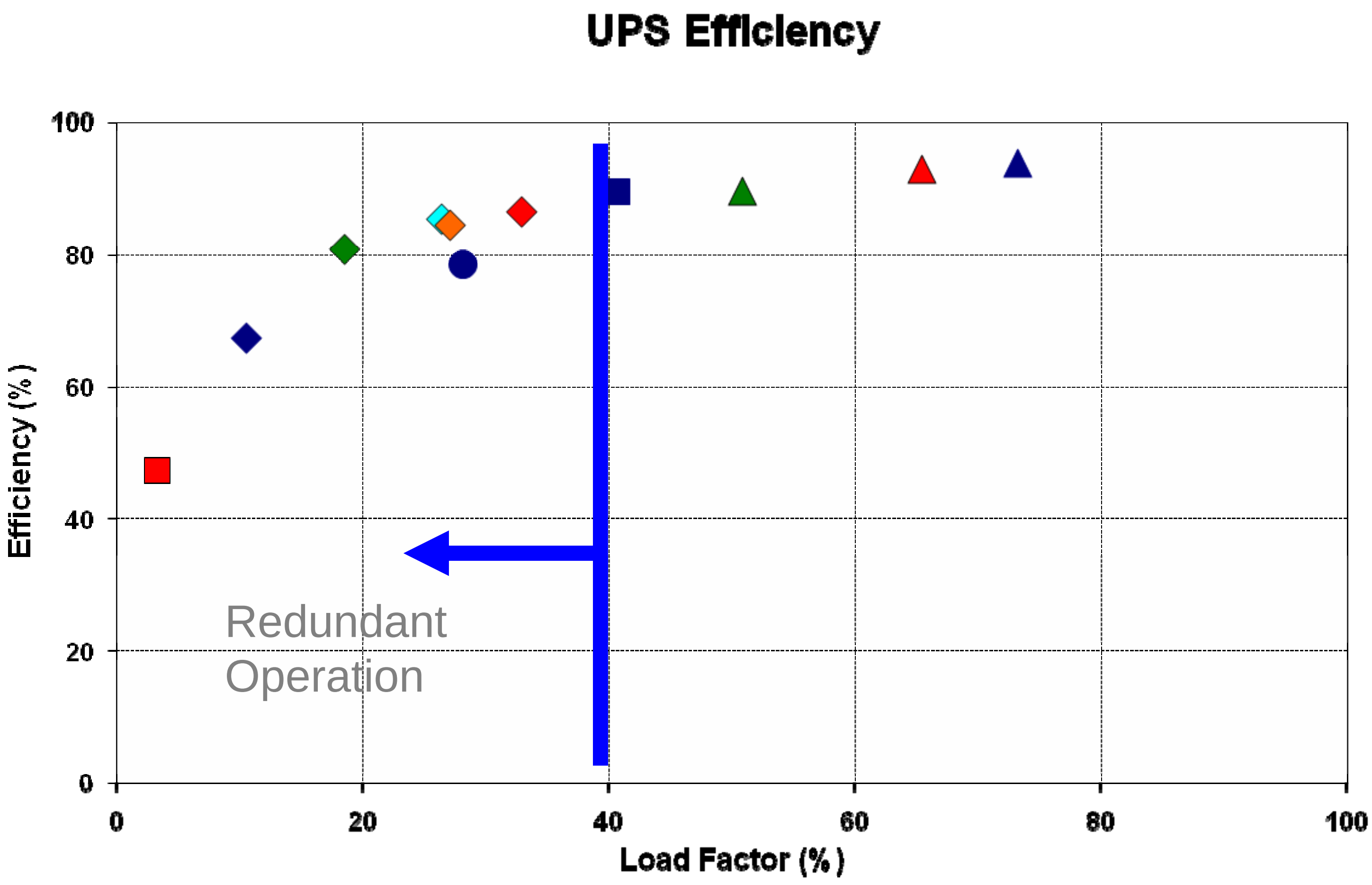
ASHRAE Prediction of Intensity Trend



Redundancy

- Understand what redundancy costs – is it worth it?
- Different strategies have different energy penalties (e.g. 2N vs. N+1)
- Redundancy in electrical distribution always puts you down the efficiency curve

Measured UPS Efficiency

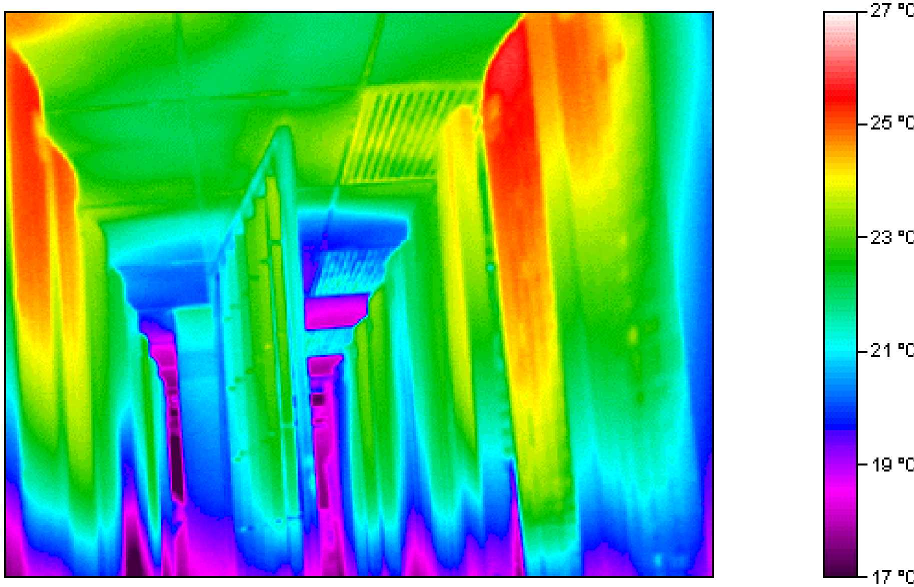


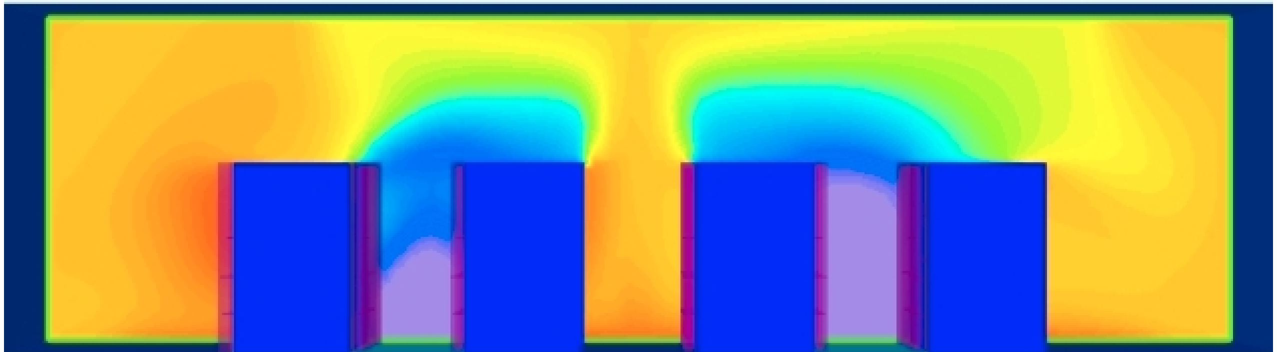
Air Flow Requirements

- Typically, much more air is circulated through computer room air conditioners than is specified by manufacturers due to mixing and short circuiting of air
- Computer manufacturers now provide ASHRAE data sheets which specify airflow and environmental requirements
- Evaluate airflow from computer room air conditioners compared to server needs

Visualizing Air Flow

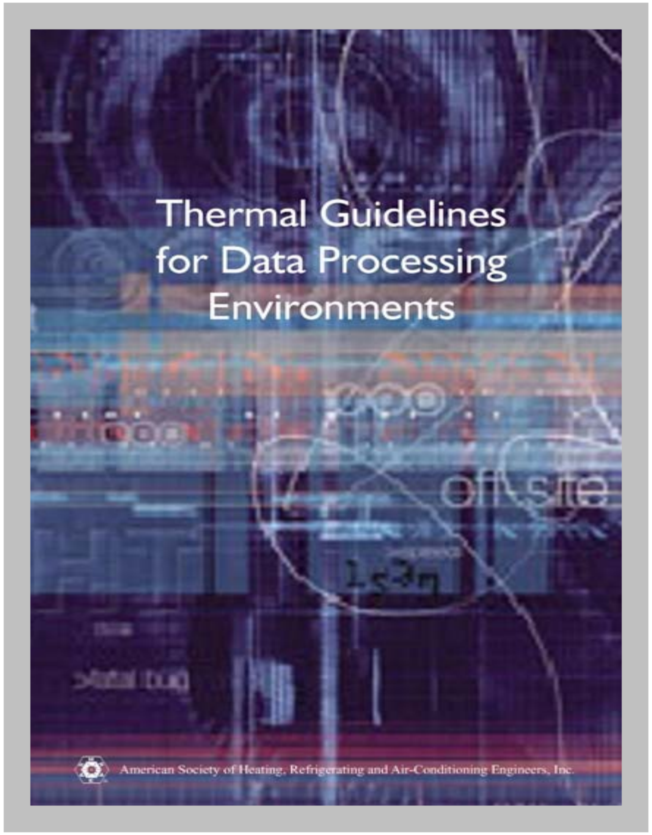
- Computational Fluid Dynamics (CFD) modeling
- Temperature sensor networks
- Infrared thermography





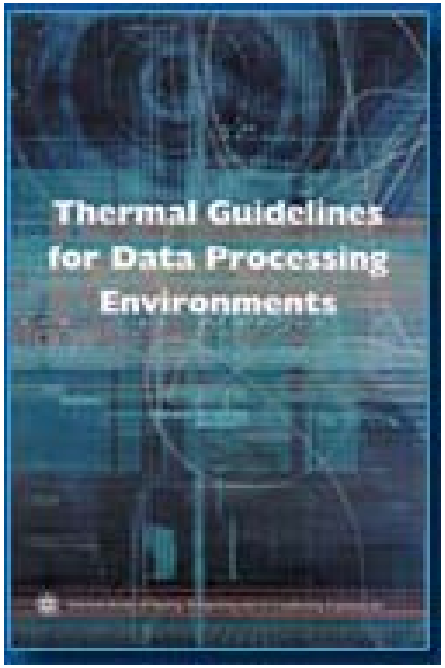
Environmental Conditions

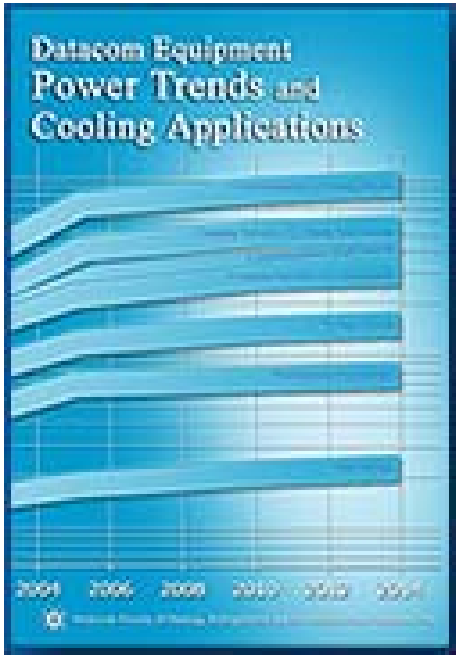
- ASHRAE - consensus from all major IT manufacturers on temperature and humidity conditions
- Recommended and Allowable ranges of temp and humidity
- Air flow required

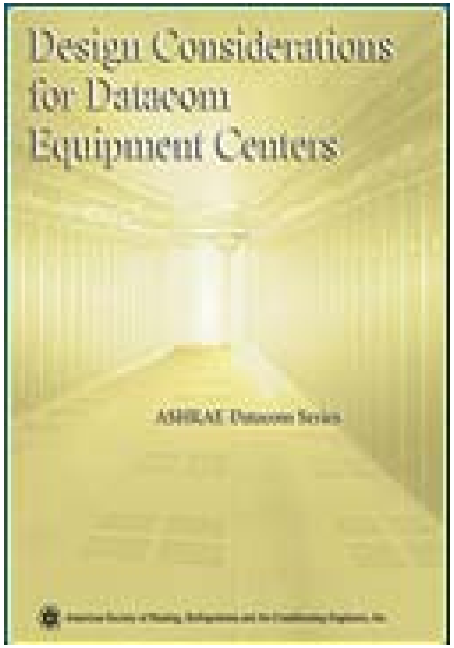


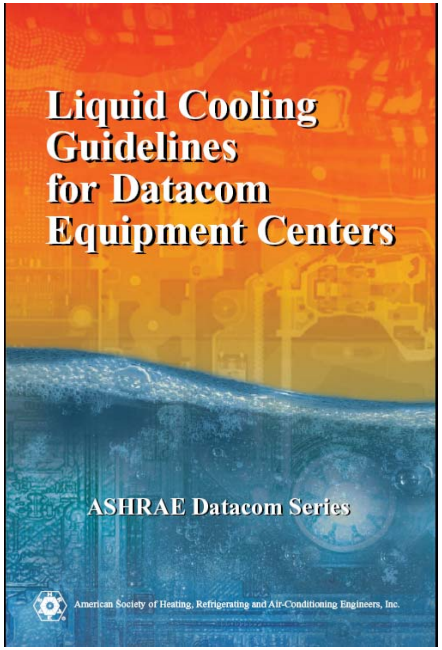
Other ASHRAE Resources

Four books published—
more in preparation





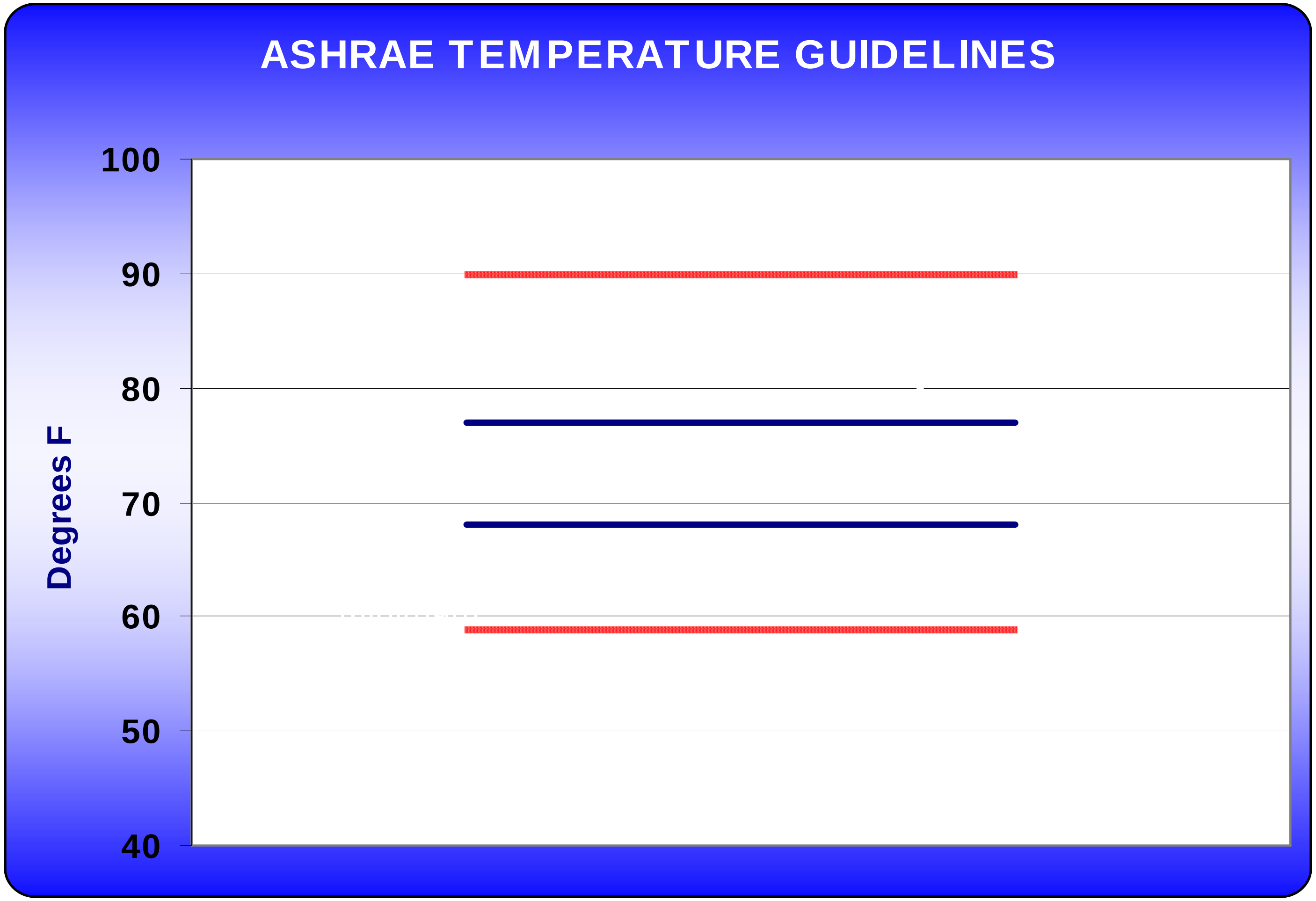




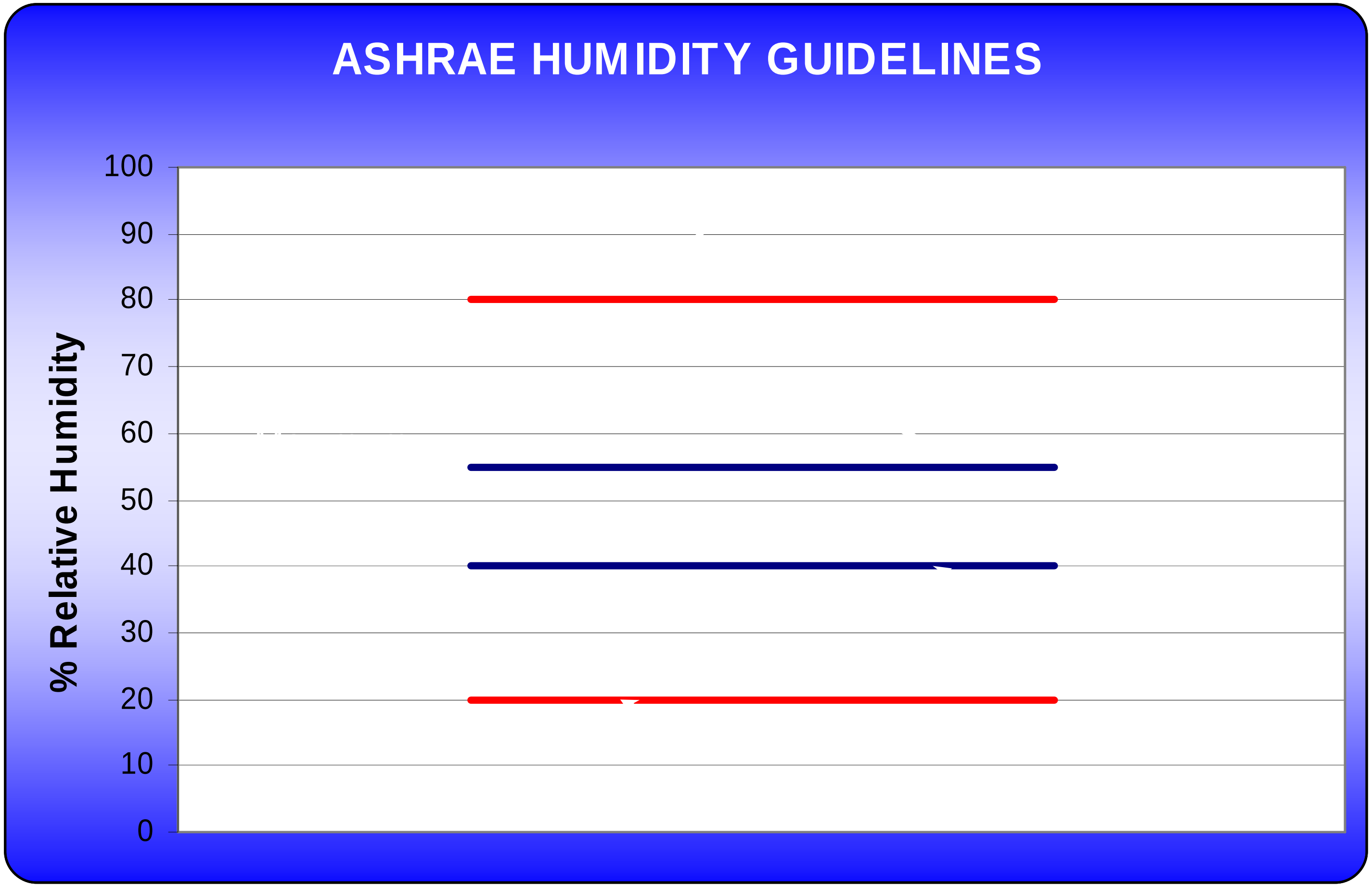
ASHRAE, Thermal Guidelines for Data Processing Environments, 2004, Datacom Equipment Power Trends and Cooling Applications, 2005, Design Considerations for Datacom Equipment Centers, 2005, Liquid Cooling Guidelines for Datacom Equipment Centers, 2006, © American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., www.ashrae.org

Order from http://tc99.ashraetcs.org/

Temperature Guidelines – *at The Inlet* to IT Equipment



Humidity Guidelines—
at The Inlet to IT Equipment



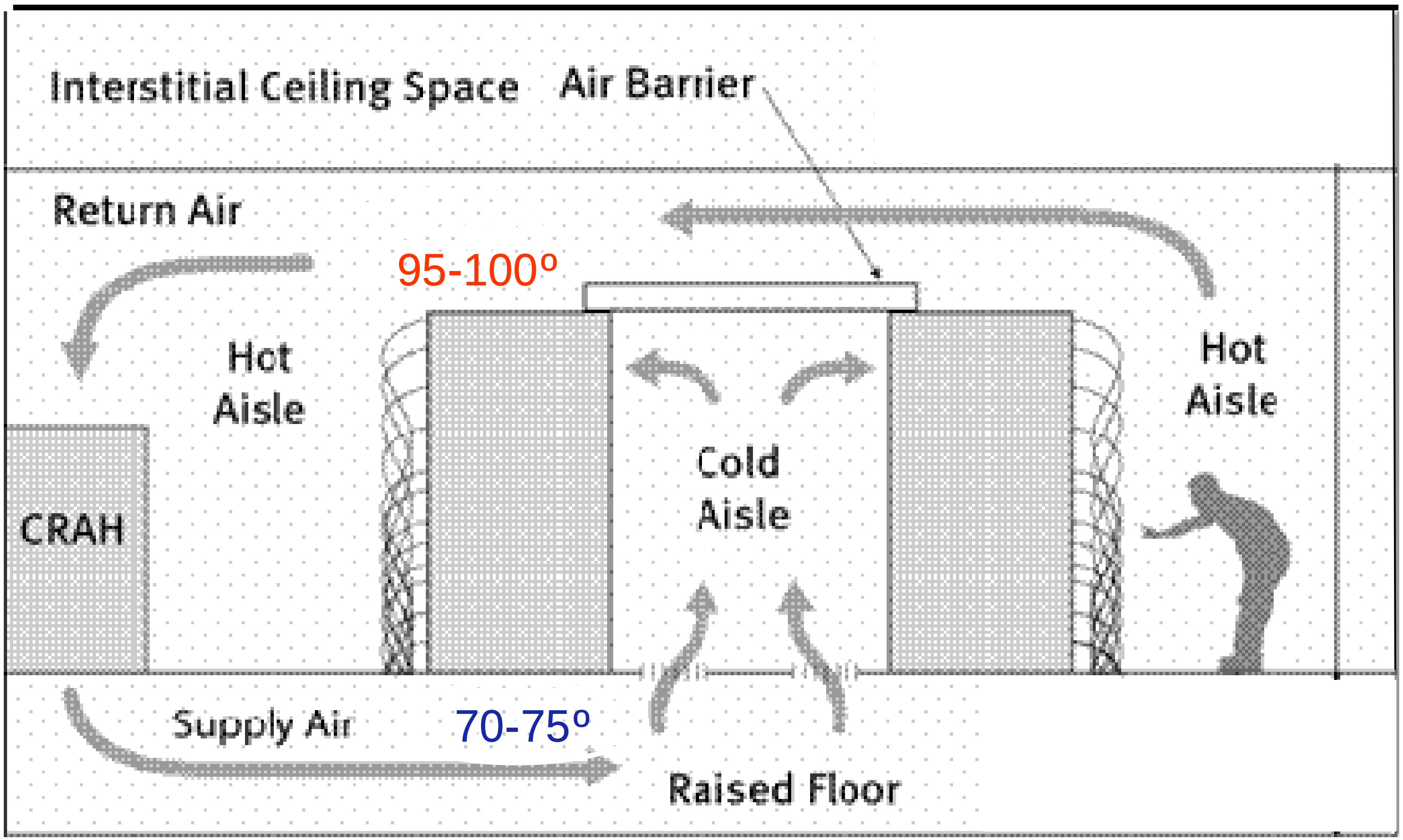
Zoning

- Some IT equipment (e.g. storage) requires tighter control
- Don’t penalize the whole center for a few pieces of equipment
- Different zones should be provided

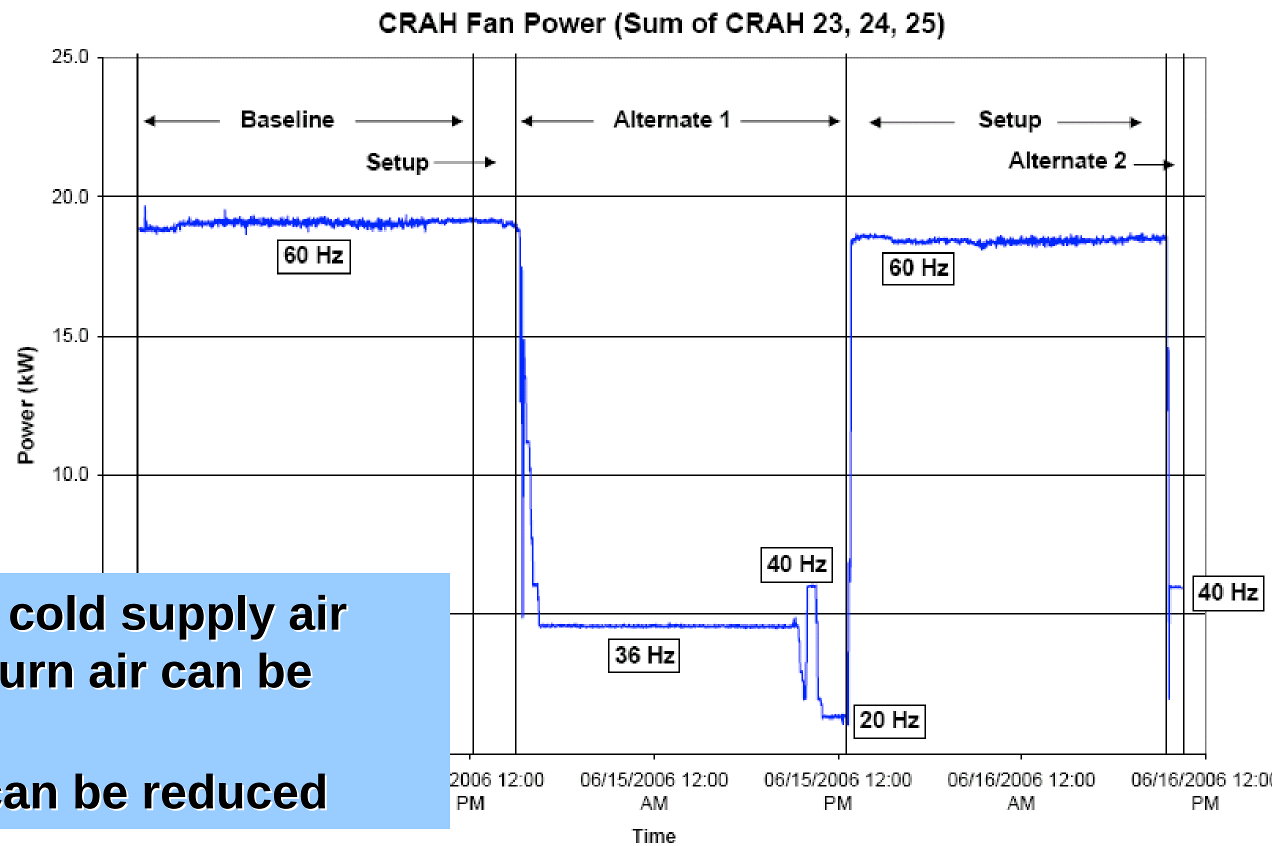
Isolating Hot and Cold

- Energy intensive IT equipment needs good isolation of “cold” inlet and “hot” discharge
- Computer room air conditioner airflow can be reduced if no mixing occurs
- Overall temperature can be raised in the data center if air is delivered to equipment without mixing
- Coils and chillers are more efficient with higher temperature differences

Best Scenario— Isolate Cold and Hot



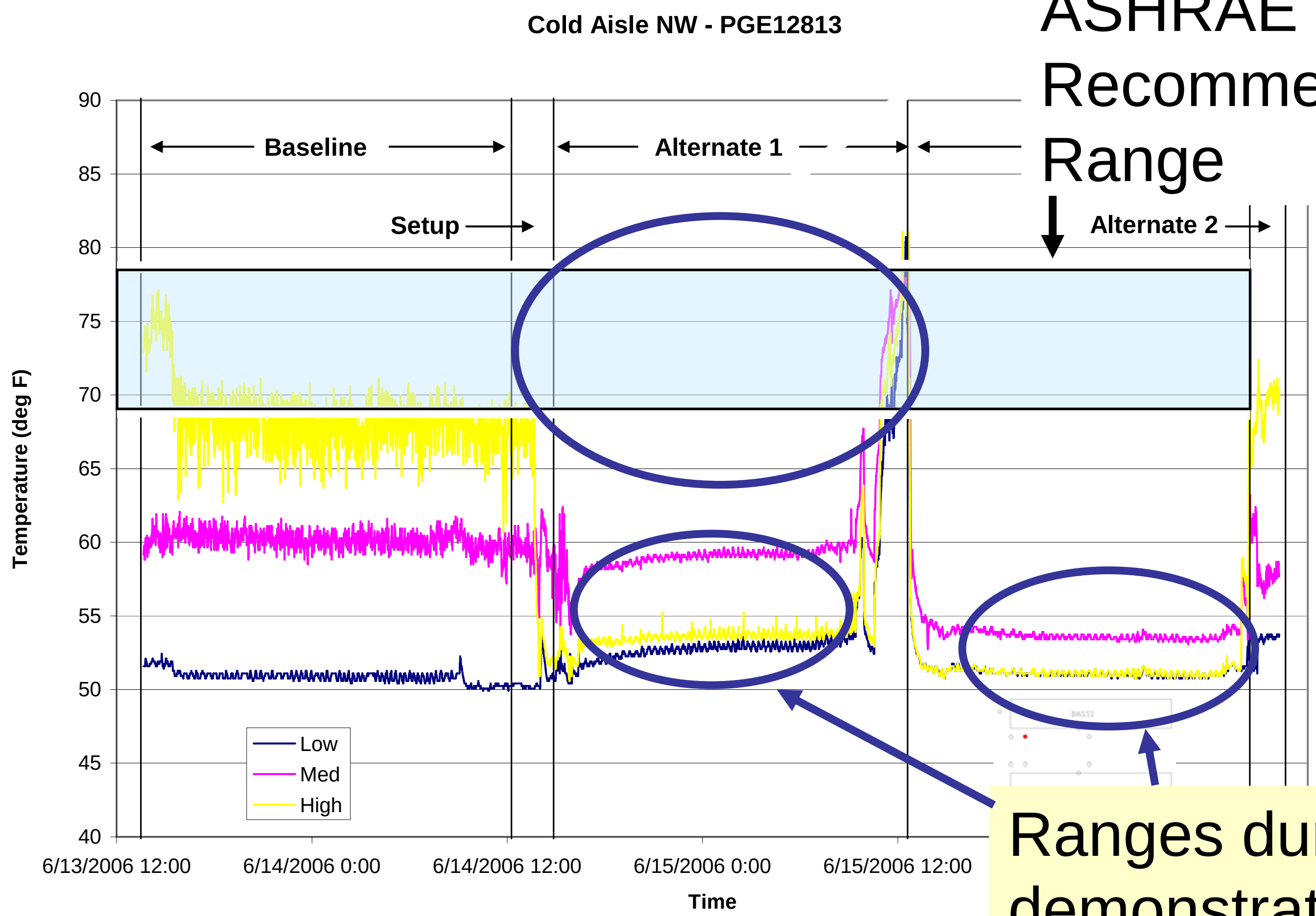
Fan Energy Savings – 75%



If mixing of cold supply air with hot return air can be eliminated-

fan speed can be reduced

Better Temperature Control Can Allow Raising the Temperature in The Entire Center

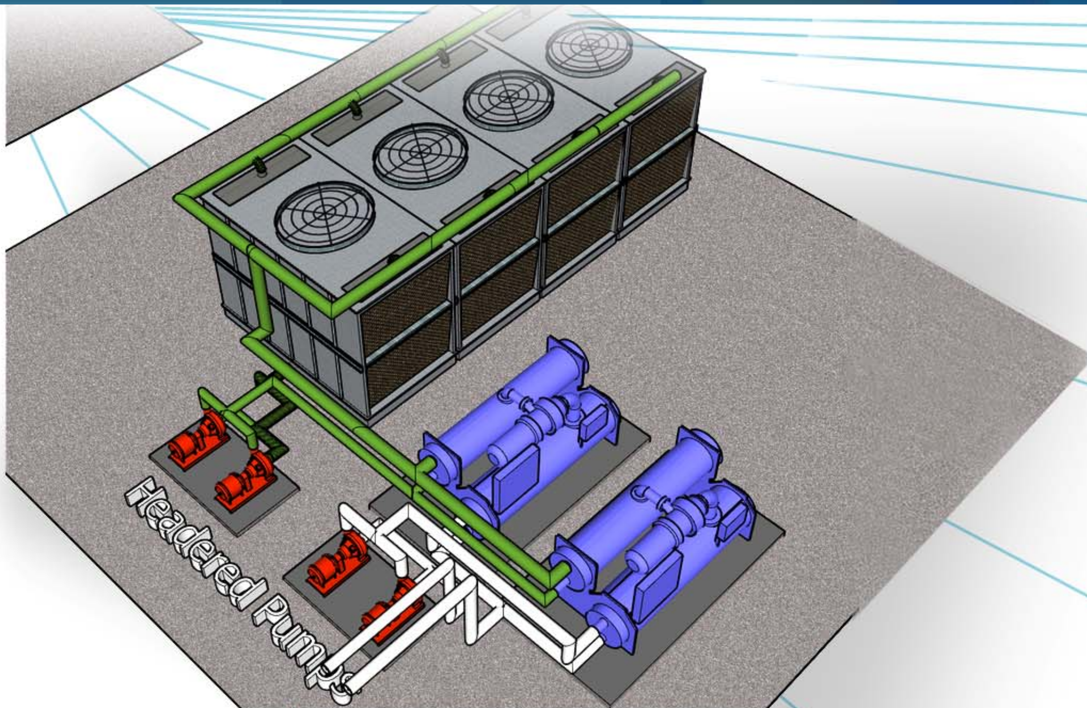


ASHRAE Recommended Range

Ranges during demonstration

Take Aways

- IT equipment loads can be improved
- Air flow delivered by computer room air conditioners must satisfy IT equipment
- Different redundancy strategies have different efficiencies
- Operating within ASHRAE guidelines can save energy
- Modern IT equipment is not as sensitive to humidity
- Isolating hot and cold can improve efficiency

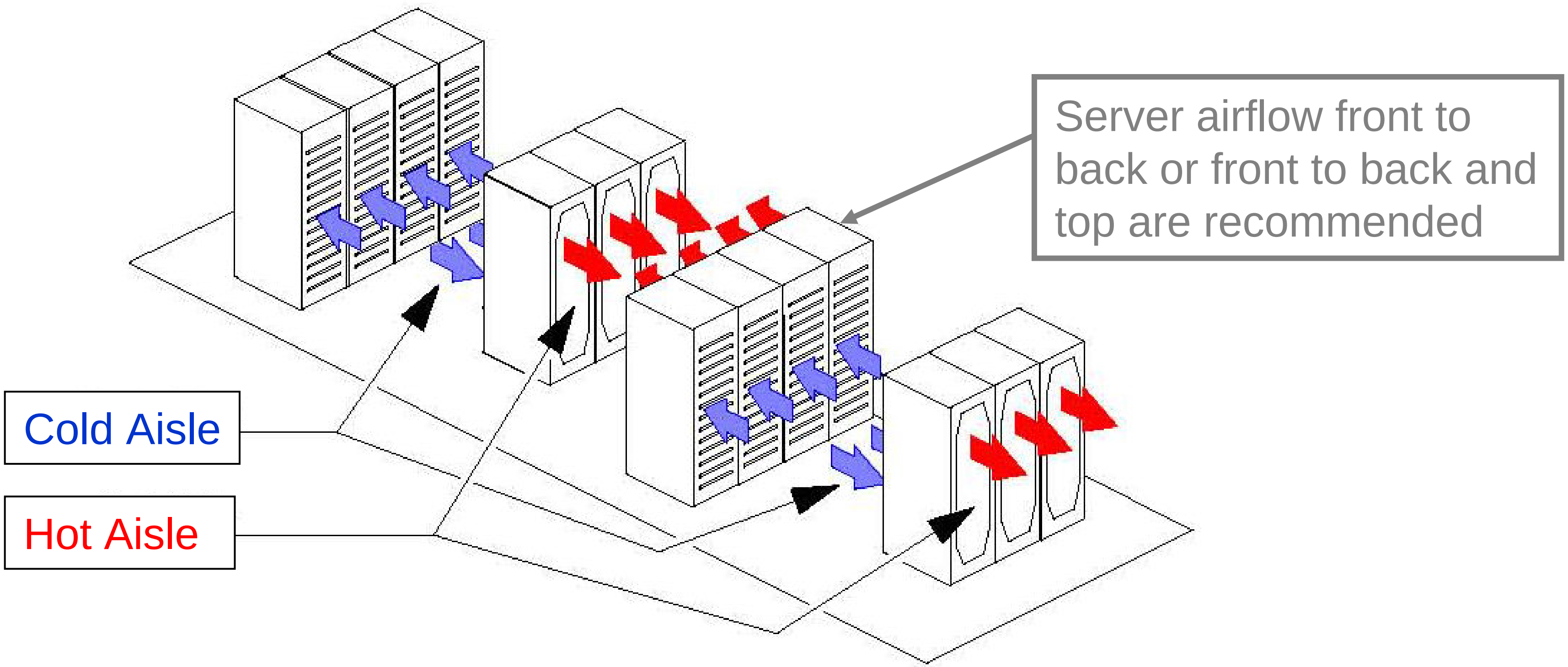


HVAC System Design

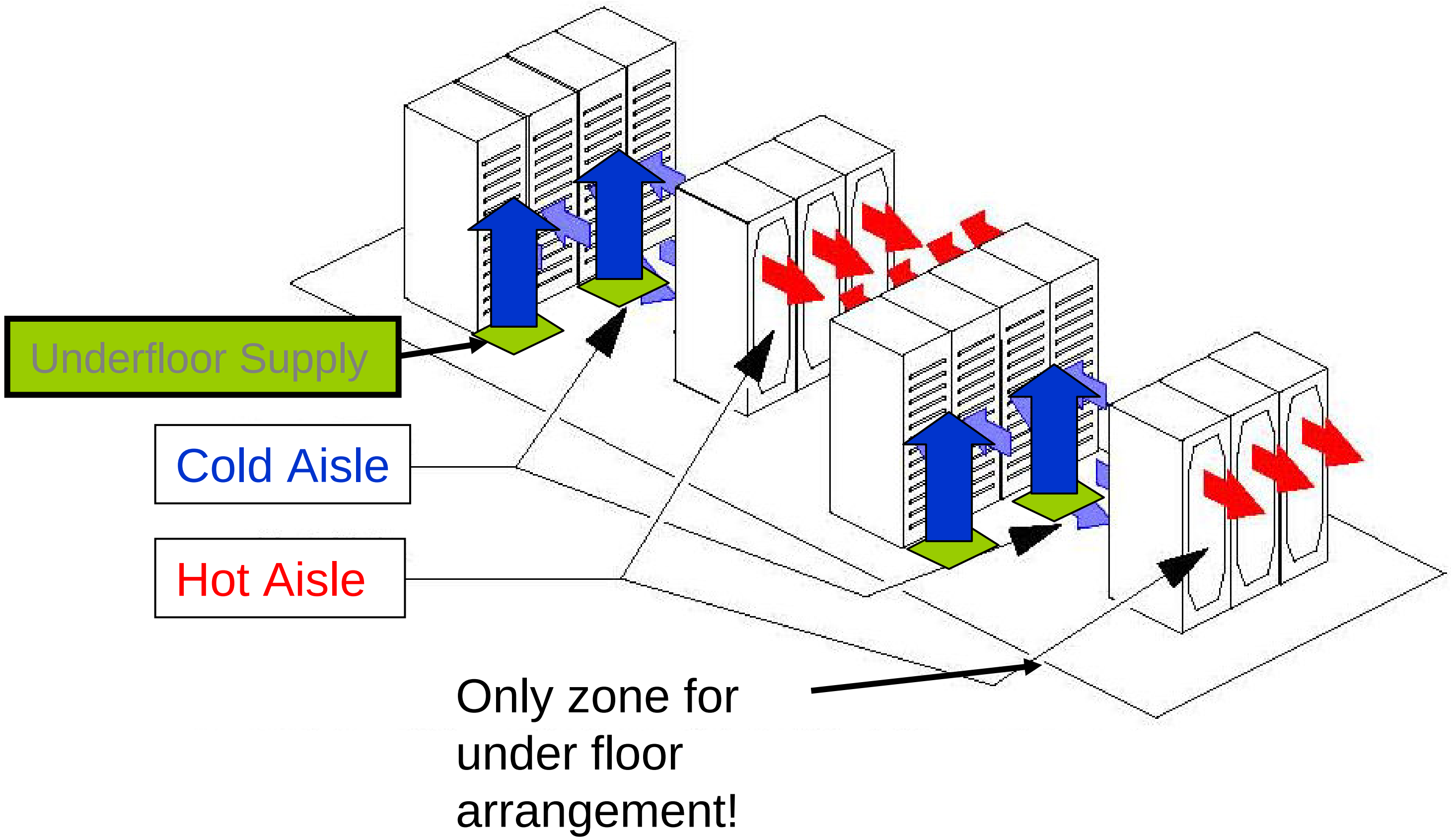
Air System Design Overview

- Data center layout
- Airflow configurations
  - Distribution: overhead or underfloor
  - Control: constant or variable volume
- Airflow issues
- Economizers
- Humidity control issues

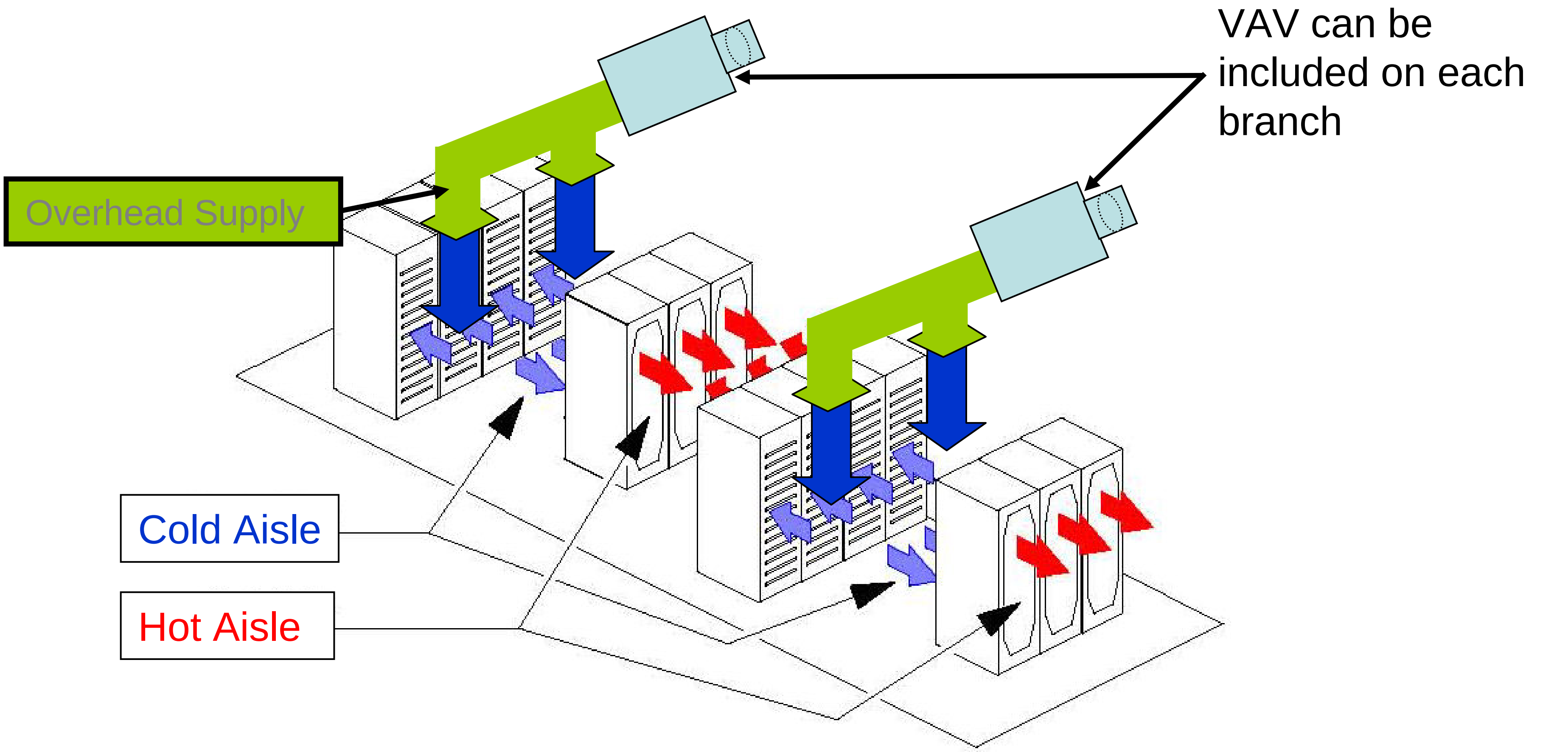
Data Center Layout



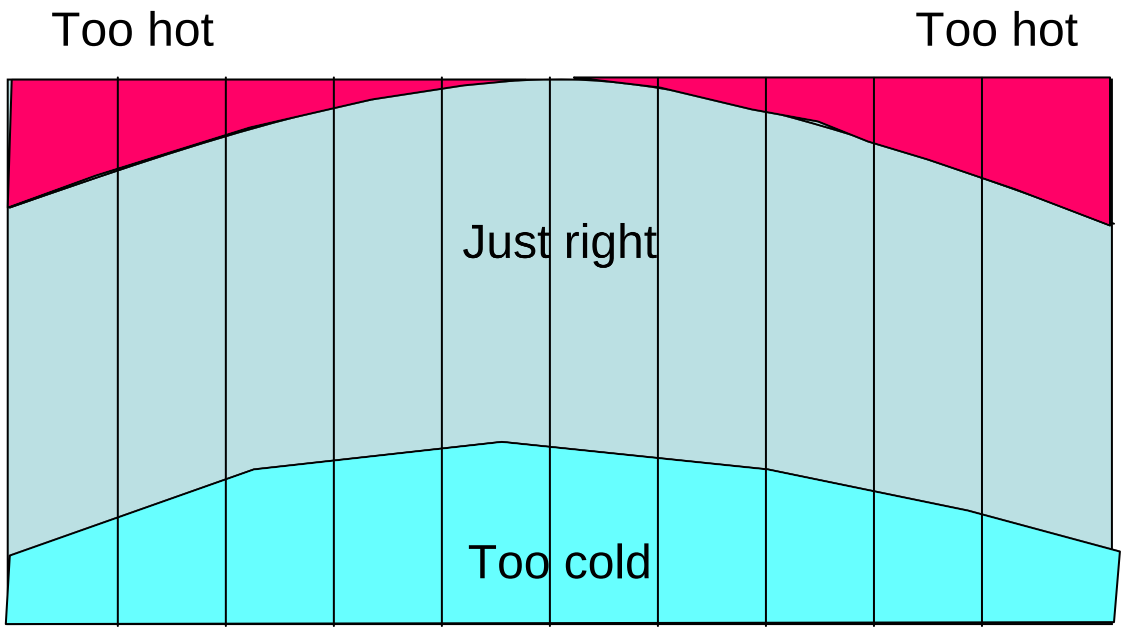
Data Center Layout



Data Center Layout



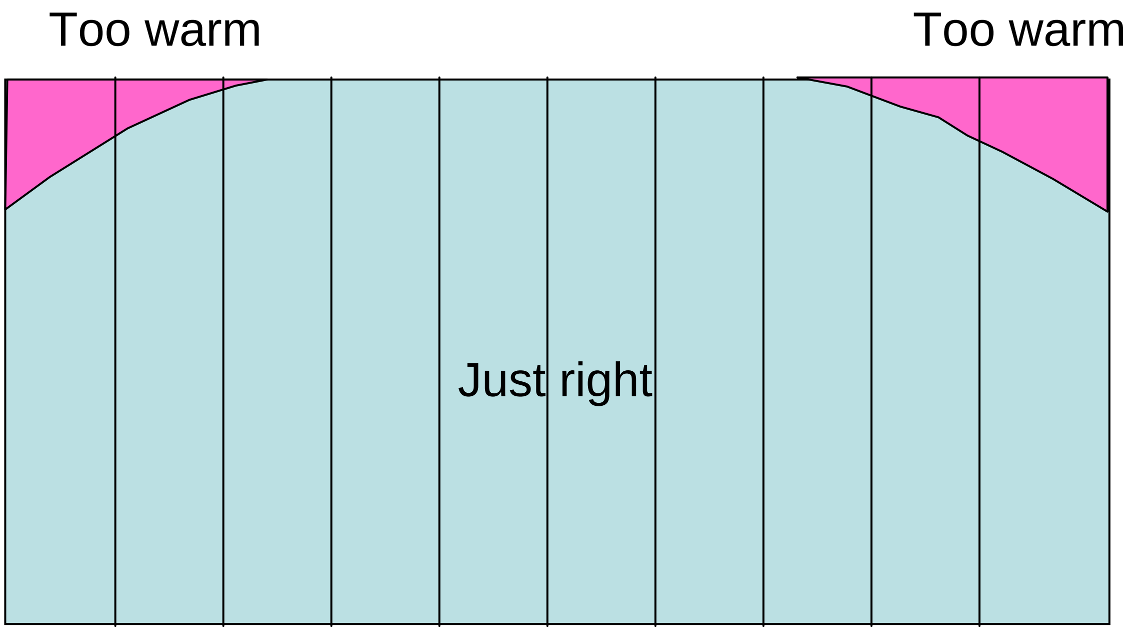
Typical Temperature Profile with Under Floor Supply



Elevation at a cold aisle looking at racks

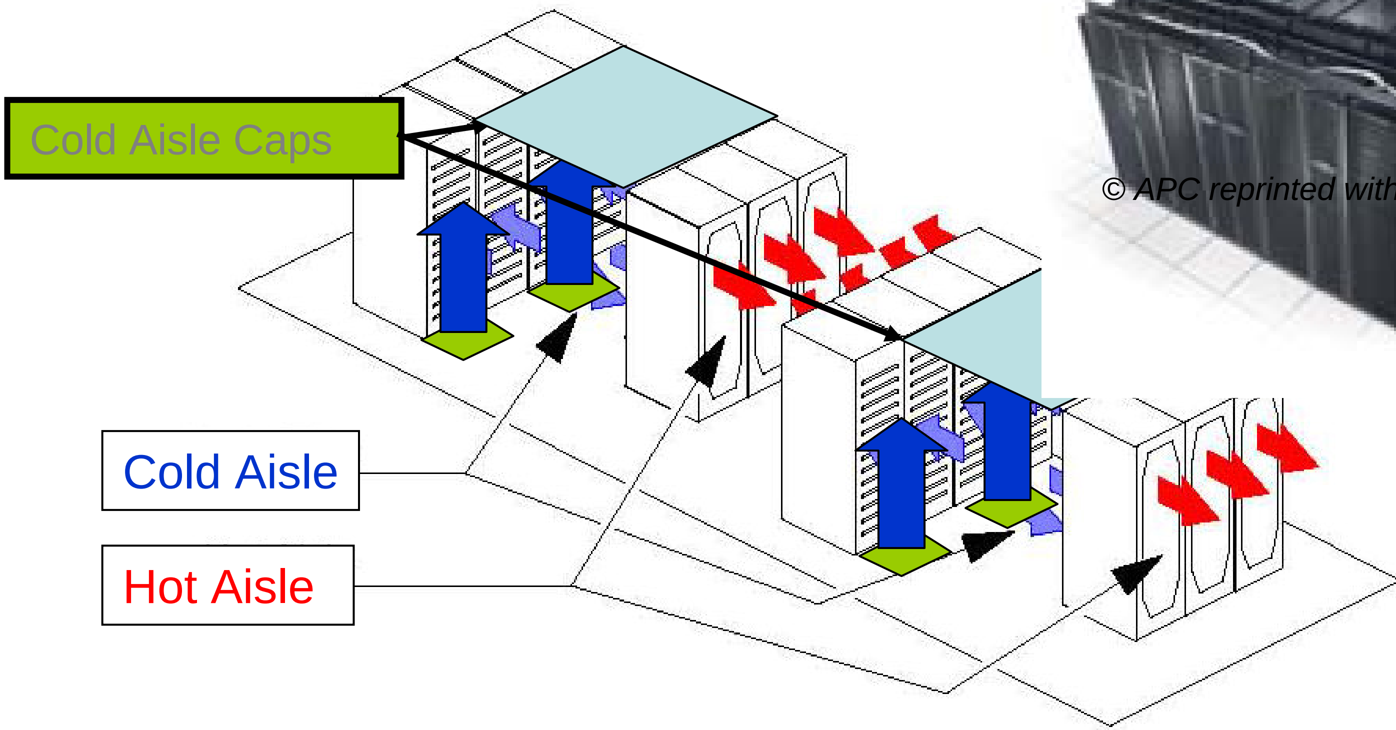
There are numerous references in ASHRAE. See for example V. Sorell et al; "Comparison of Overhead and Underfloor Air Delivery Systems in a Data Center Environment Using CFD Modeling"; ASHRAE Symposium Paper DE-05-11-5; 2005

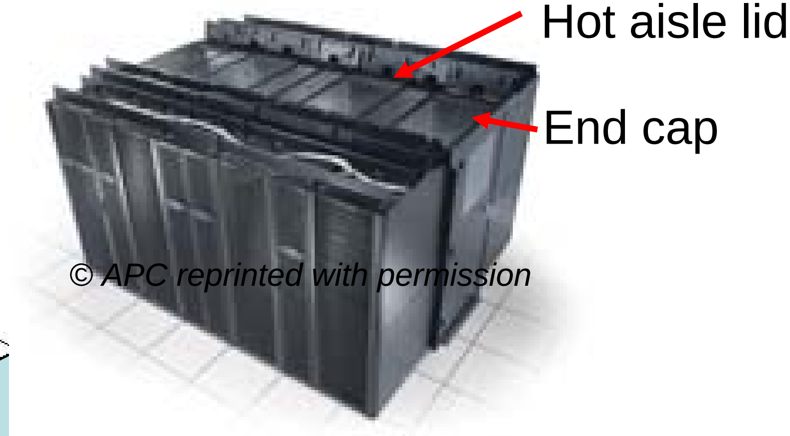
Typical Temperature Profile with Overhead Supply



Elevation at a cold aisle looking at racks

Aisle Air Containment





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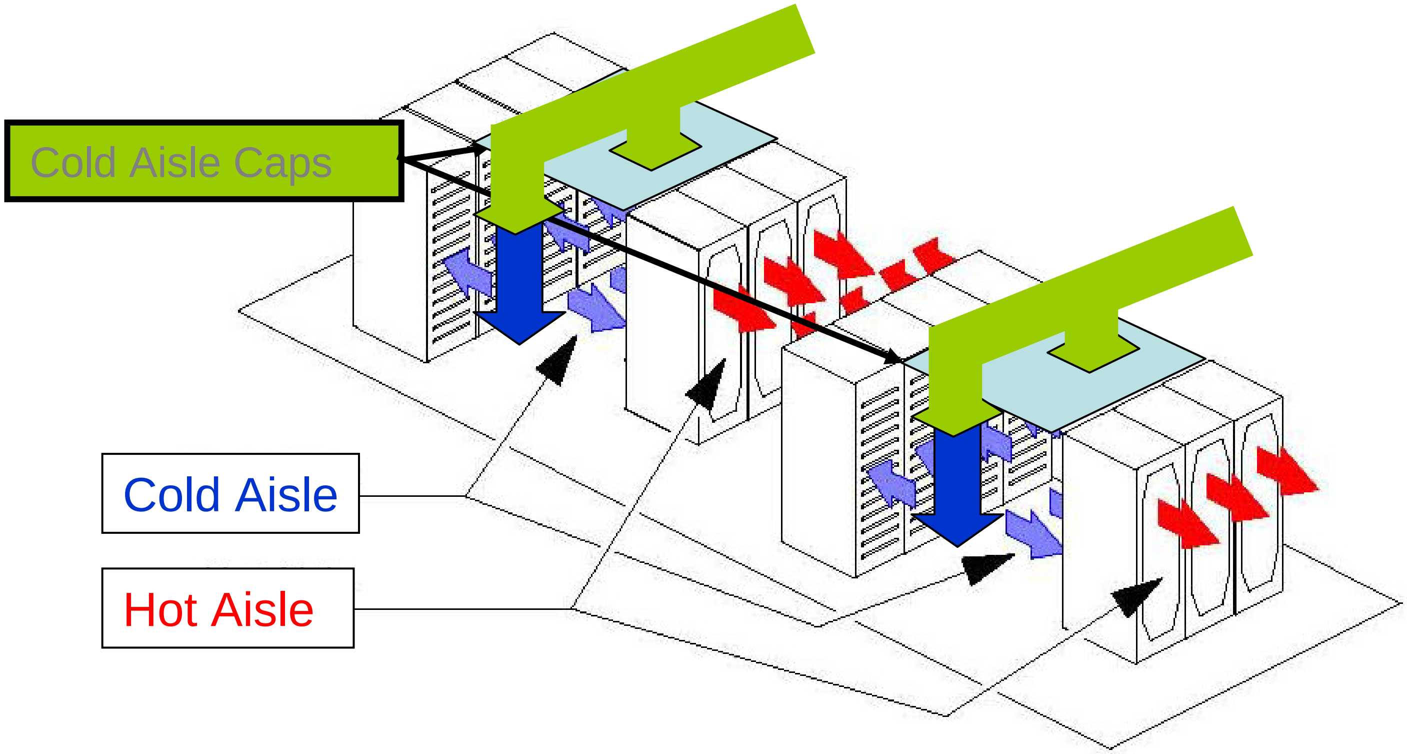


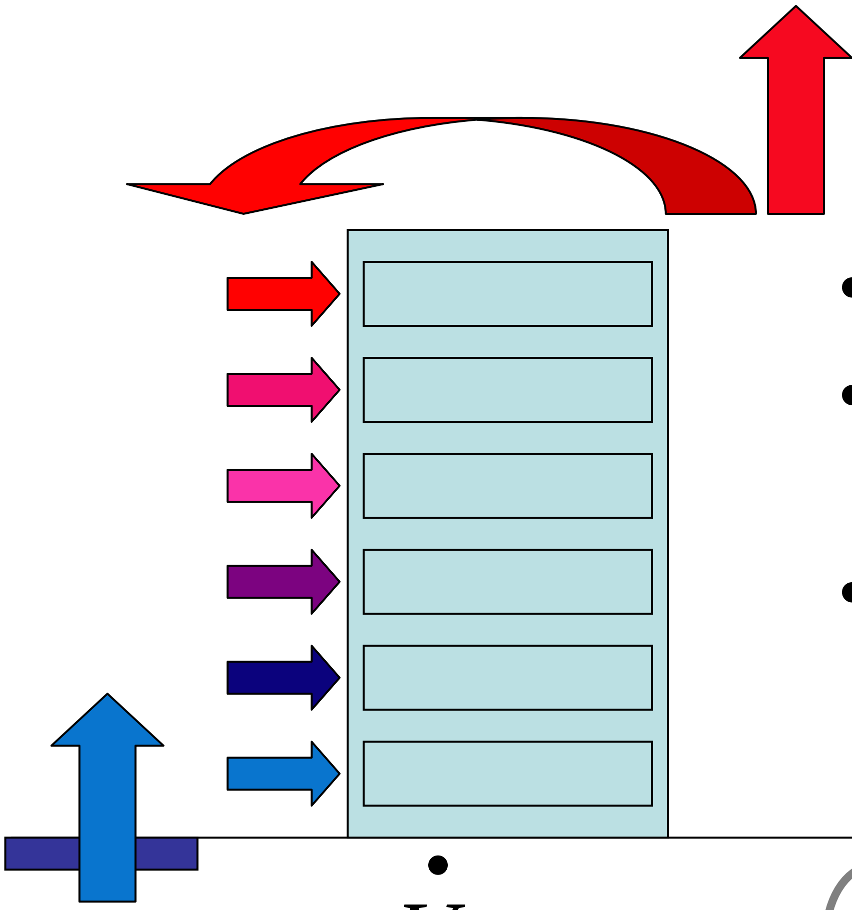
Overhead (OH) vs. Underfloor (UF)

Issue	**Overhead (OH) Supply**	**Underfloor (UF) Supply**
Capacity	Limited by space and aisle velocity.	Limited by free area of floor tiles.
Balancing	Continuous on both outlet and branch.	Usually limited to incremental changes by diffuser type. Some tiles have balancing dampers. Also underfloor velocities can starve floor grilles!
Control	Up to one pressure zone by branch.	Only one pressure zone per floor, can provide multiple temperature zones.
Temperature Control	Most uniform.	Commonly cold at bottom and hot at top.
First Cost	Best (if you eliminate the floor).	Generally worse.
Energy Cost	Best.	Worst.
Aisle Capping	Hot or cold aisle possible.	Hot or cold aisle possible.

Airflow Design Disjoint

- IT departments select servers and racks – each having airflow requirements
- Engineers size the facility fans and cooling capacity
- What's missing in this picture?

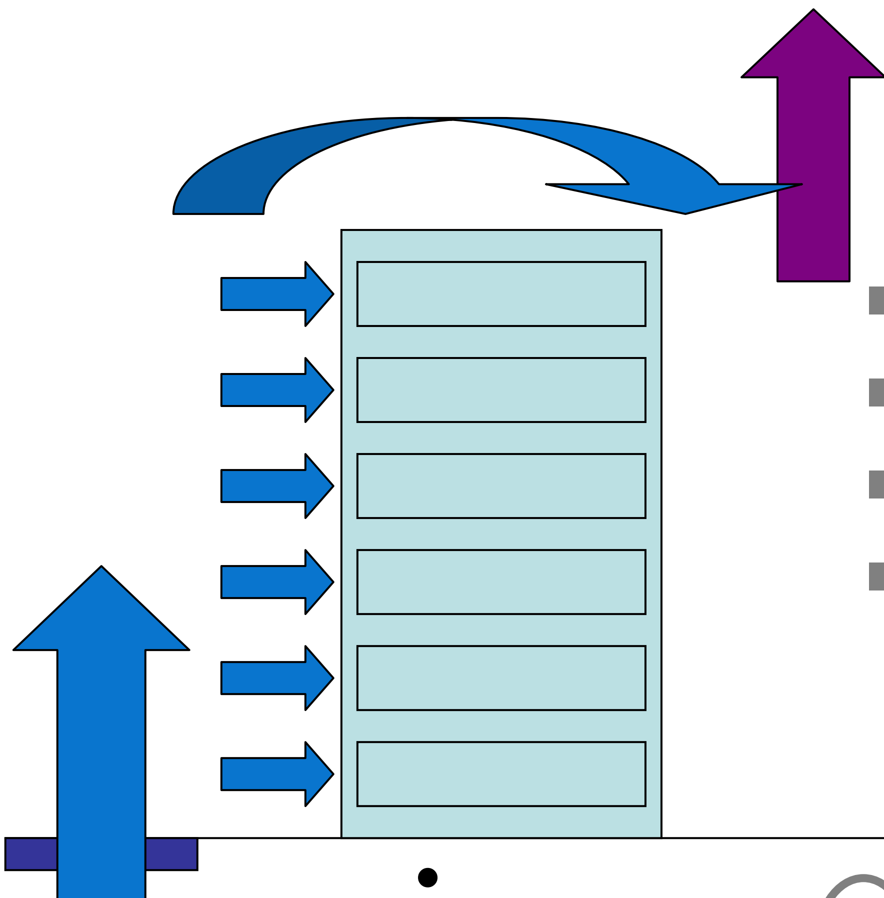
Airflow Using Constant Volume Systems



- Hot spots
- Higher hot aisle temperature
- Possible equipment failure or degradation

$$\dot{V}_{HVAC\_Supply} < \sum \dot{V}_{Servers}$$

Airflow Using Constant Volume Systems



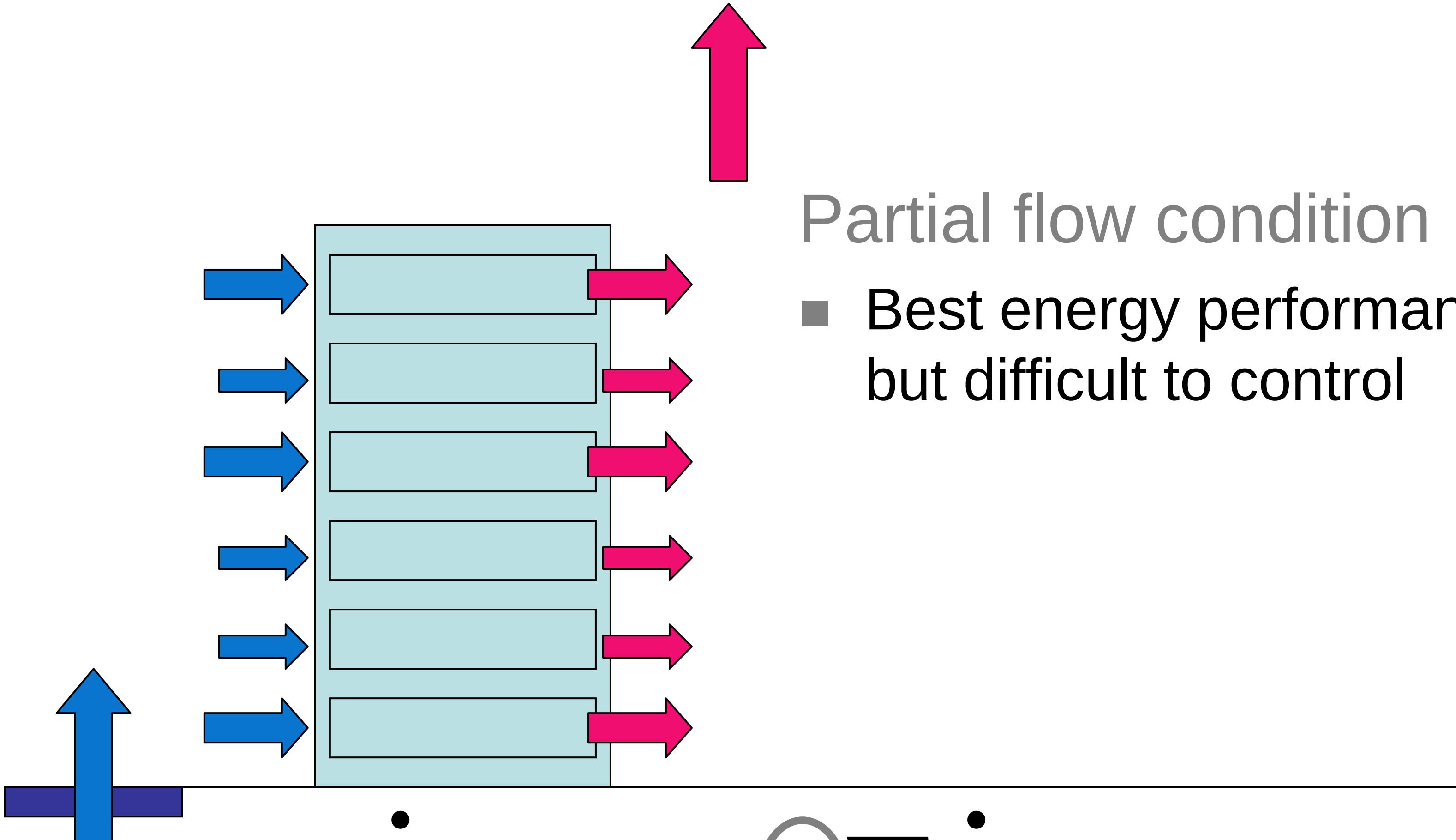
- Least hot spots
- Higher air velocities
- Higher fan energy
- Reduced economizer effectiveness (due to lower return temperatures)

$$\dot{V}_{HVAC\_Supply} > \sum \dot{V}_{Servers}$$

Airflow Using Constant Volume Systems

- Note most of these observations apply to overhead and underfloor distribution
- With constant volume fans on the servers you can only be right at one condition of server loading!
- The solution is to employ variable speed server and distribution fans…

Airflow Using Variable Volume Systems



Partial flow condition

- Best energy performance but difficult to control

$$\dot{V}_{HVAC\_Supply} > \sum \dot{V}_{Servers}$$

How Do You Balance Airflow?

- Spreadsheet
- CFD
- Monitoring/Site Measurements

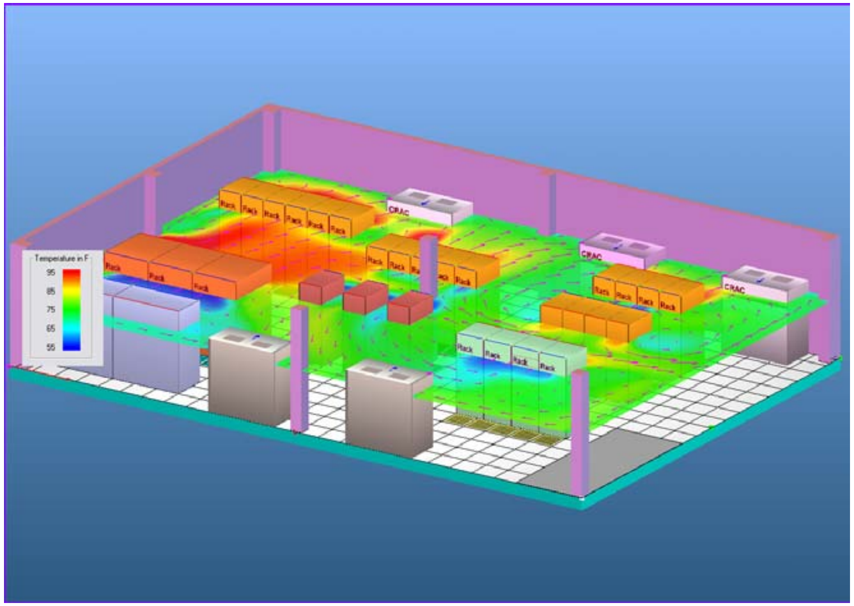


Image from TileFlow
http://www.inres.com/Products/TileFlow/tileflow.html,
Used with permission from Innovative Research, Inc.

ASHRAE Thermal Report

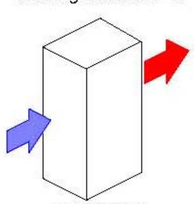
XYZ Co. Model abc Server: Representative Configurations

	Condition								
	Voltage 110 Volts								
	Typical Heat Release	Airflow[a], Nominal		Airflow, Maximum at 35°C		Weight		Overall System Dimensions[b] (W × D × H)	
Description	watts	cfm	(m^3/h)	cfm	(m^3/h)	lbs	kg	in.	mm
Minimum Configuration	*1765*	*400*	*680*	*600*	*1020*	*896*	*406*	*30 × 40 × 72*	*762 × 1016 × 1828*
Full Configuration	*10740*	*750*	*1275*	*1125*	*1913*	*1528*	*693*	*61 × 40 × 72*	*1549 × 1016 × 1828*
Typical Configuration	*5040*	*555*	*943*	*833*	*1415*	*1040*	*472*	*30 × 40 × 72*	*762 × 1016 × 1828*

ASHRAE Class

1, 2, 3

Airflow Diagram
Cooling scheme F-R



Minimum Configuration	*1 CPU-A, 1 GB, 2 I/O*
Full Configuration	*8 CPU-B, 16 GB, 64 I/O (2 GB cards, 2 frames)*
Typical Configuration	*4 CPU-A, 8 GB, 32 I/O (2 GB cards, 1 frame)*

a. The airflow values are for an air density of 1.2 kg/m^3 (0.075 lb/ft^3). This corresponds to air at 20°C (68°F), 101.3 kPA (14.7 psia), and 50% relative humidity.
b. Footprint does not include service clearance or cable management, which is zero on the sides, 46 in. (1168 mm) in the front, and 40 in. (1016 mm) in the rear.

From ASHRAE's Thermal Guidelines for Data Processing Environments

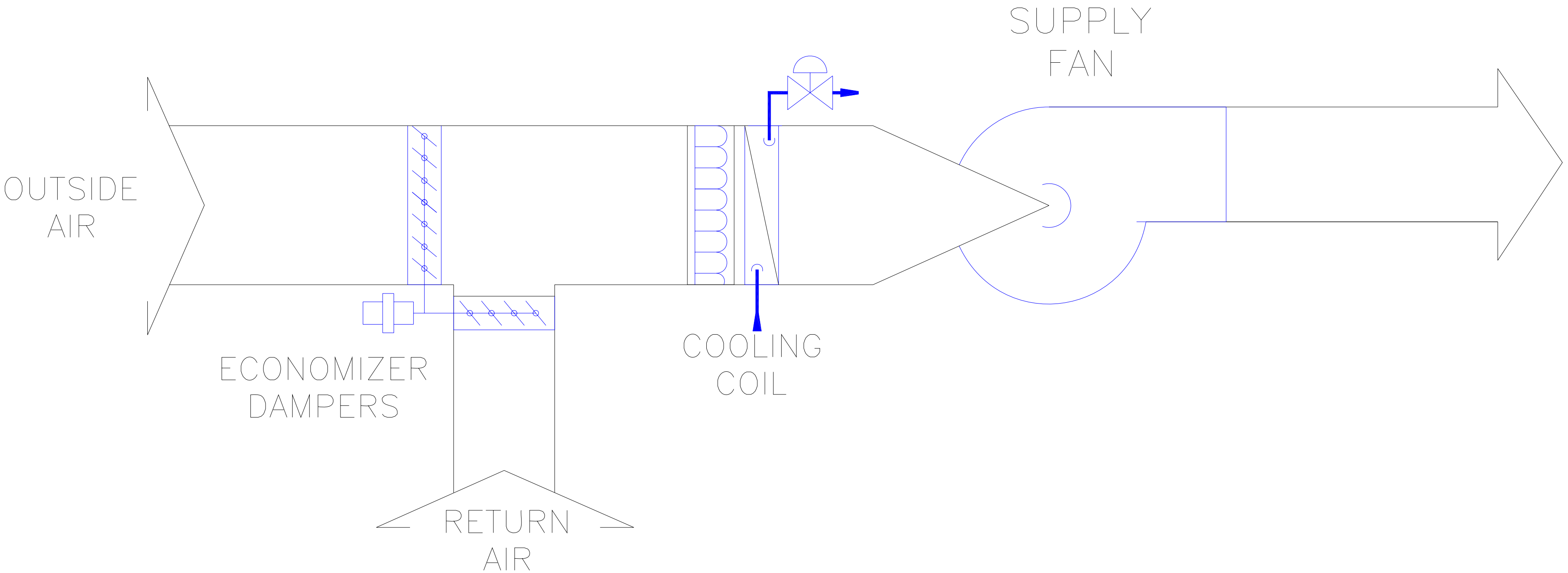
What's the IT Equipment Airflow?

	SUN	SUN	DELL	DELL
	V490	V240	2850	6850
num fans	9	3	n/a	n/a
total CFM (max)	150	55.65	42	185
total CFM (min)			27	126
fan speed	single speed	variable	2 speed	2 speed
fan control	n/a	inlet temp.	77F inlet	77F inlet
Form Factor (in U's)	5	2	2	4
heat min config (btuh)		798		454
heat max config (btuh)	5,459	1,639	2,222	4,236
heat max (watts)	1,599	480	651	1,241
dT min config	-	13	-	3
dT max config	33	27	48	21
servers per rack	8	21	21	10
CFM/rack (hi inlet temp)	1,200	1,169	882	1,850
CFM/rack (low inlet temp)	1,200		567	1,260
max load / rack (kW)	13	10	14	12

Best air delivery practices

- Arrange racks in hot aisle/cold aisle configuration
- Try to match or exceed server airflow by aisle
  - Get thermal report data from IT if possible
  - Plan for worst case
- Get variable speed or two speed fans on servers if possible
- Provide variable airflow fans for AC unit supply
  - Also consider using air handlers rather than CRACs for improved performance (to be elaborated on later)
- Use overhead supply where possible
- Provide isolation of hot and cold spaces
- Plug floor leaks and provide blank off plates in racks
- Draw return from as high as possible
- Use CFD to inform design and operation

Air-side Economizer

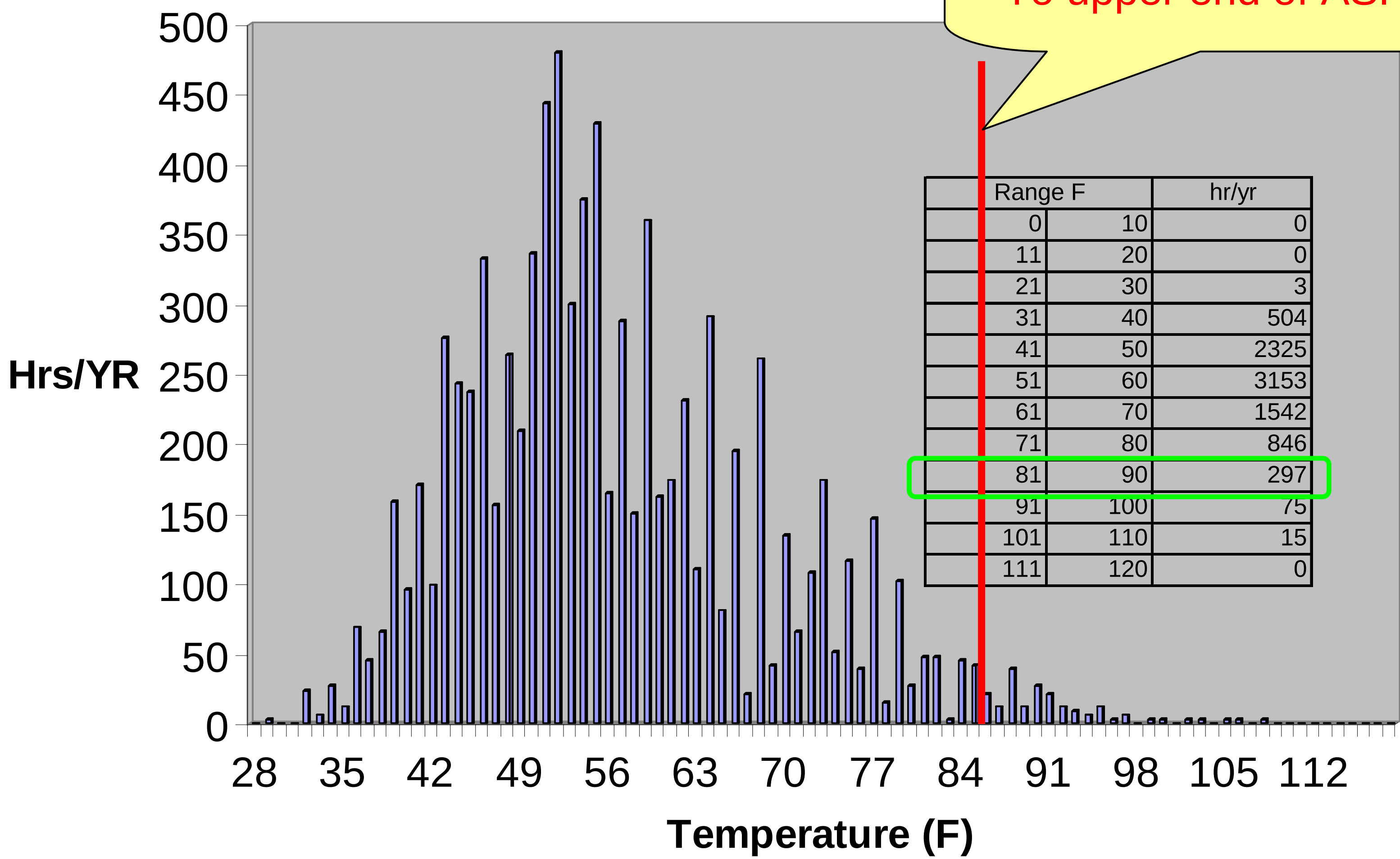


Air-Side Economizer issues

- In California many hours of free cooling
- Concerns over contamination
- Concerns over humidity control
- ASHRAE is addressing these concerns
- LBNL demonstration studied the issues

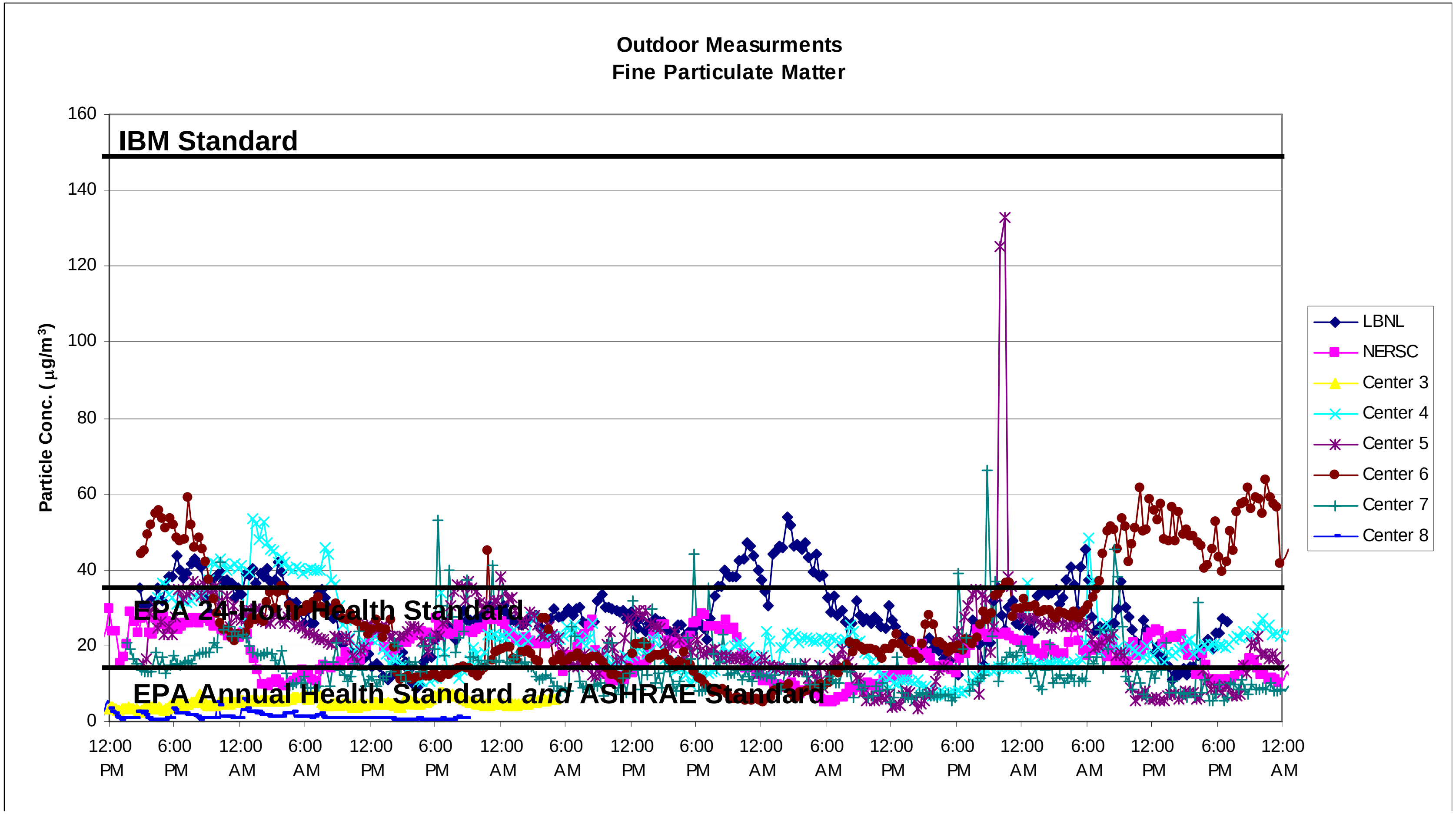
Berkeley Weather

Set Inlet Temperature
To upper end of ASHRAE

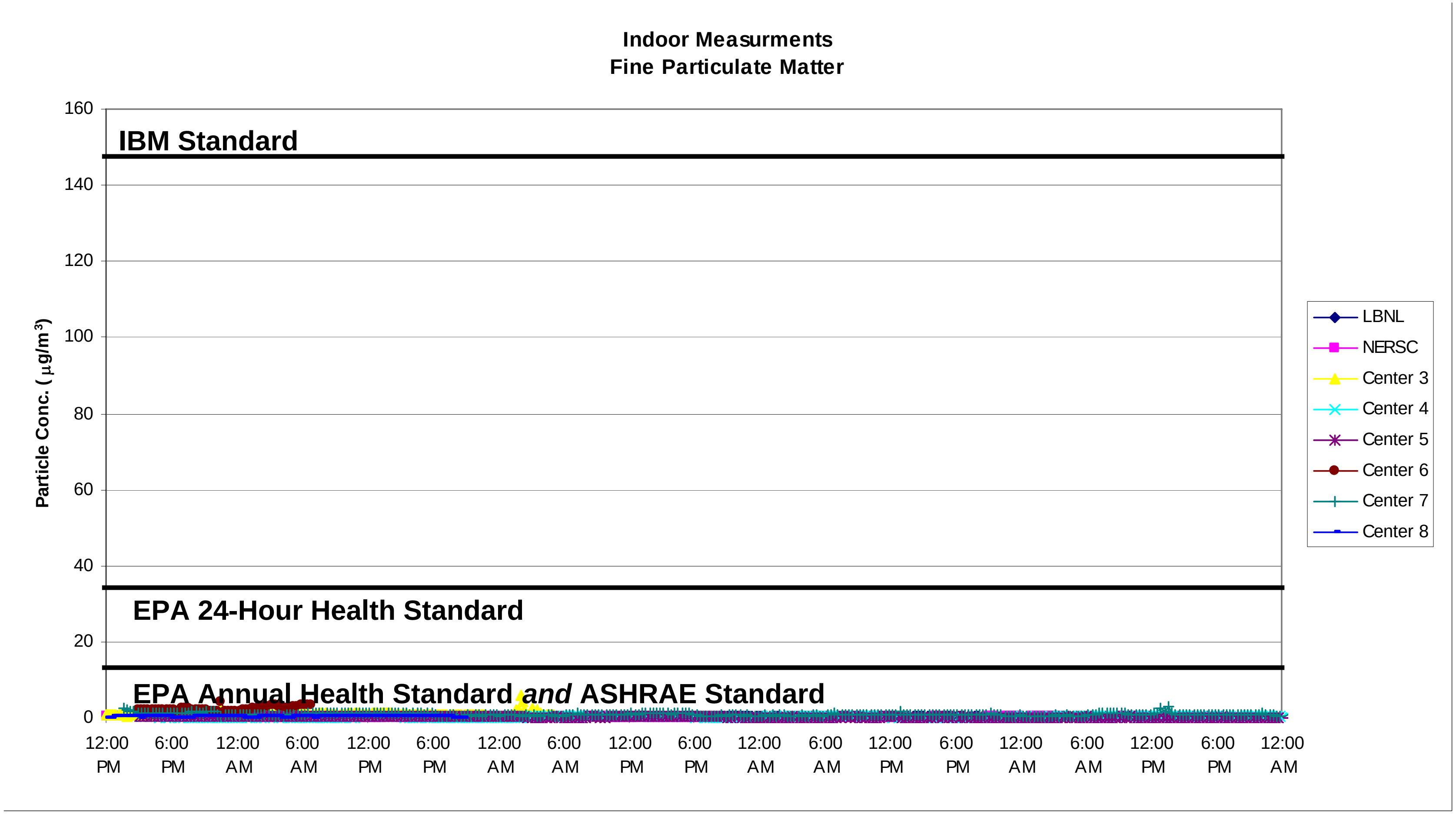


Range F		hr/yr
0	10	0
11	20	0
21	30	3
31	40	504
41	50	2325
51	60	3153
61	70	1542
71	80	846
81	90	297
91	100	75
101	110	15
111	120	0

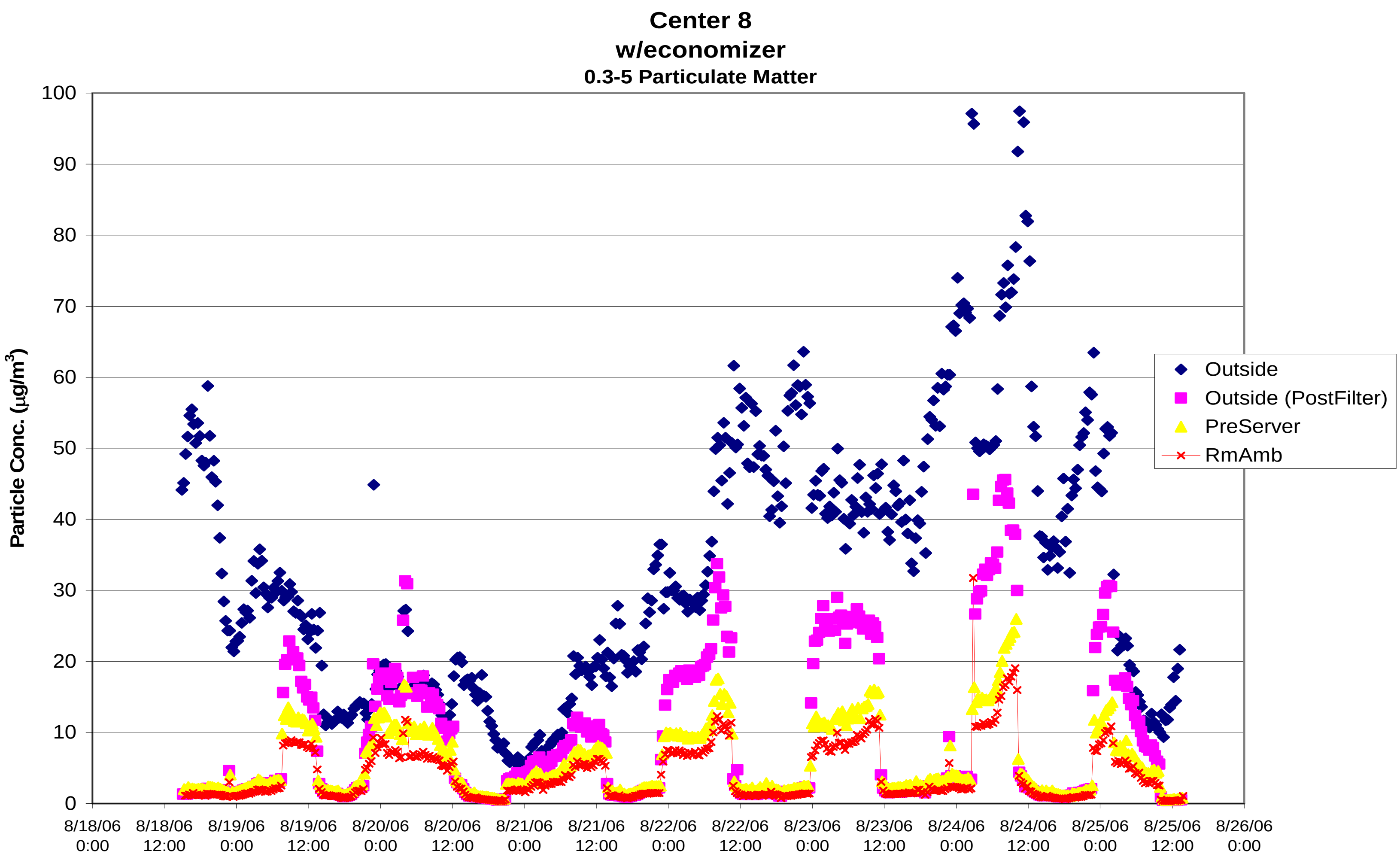
Outdoor measurements



Measurements inside the centers



Data center w/economizer



Design Conditions at the Inlet to IT Equipment

Table 2.1
Class 1, Class 2 and NEBS Design Conditions

Condition	Class 1 / Class 2		NEBS	
	Allowable Level	**Recommended Level**	**Allowable Level**	**Recommended Level**
Temperature control range	59°F – 90°F[a,f] (Class 1) 50°F – 95°F[a,f] (Class 2)	68°F – 77°F[a]	41°F – 104°F[c,f]	65°F – 80°F[d]
Maximum temperature rate of change	9°F. per hour[a]		2.9°F/min. [d]	
Relative humidity control range	20% - 80% 63°F. Max Dewpoint[a] (Class 1) 70°F. Max Dewpoint[a] (Class 2)	40% - 55%[a]	5% to 85% 82°F Max Dewpoint[c]	Max 55%[e]
Filtration quality	65%, min. 30%[b] (MERV 11, min. MERV 8)[b]			

[a]These conditions are inlet conditions recommended in the ASHRAE Publication *Thermal Guidelines for Data Processing Environments* (ASHRAE, 2004).
[b]Percentage values per ASHRAE *Standard* 52.1 dust-spot efficiency test. MERV values per ASHRAE Standard 52.2. Refer to Table 8.4 of this publication for the correspondence between MERV, ASHRAE 52.1 & ASHRAE 52.2 Filtration Standards.
[c]Telecordia 2002 GR-63-CORE
[d]Telecordia 2001 GR-3028-CORE
[e]Generally accepted telecom practice. Telecom central offices are not generally humidified, but grounding of personnel is common practice to reduce ESD.
[f]Refer to Figure 2.2 for temperature derating with altitude

Break